

AD611063

REPORT 67

JOSEPH KAYE & COMPANY, INC.
737 Concord Avenue
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HEAT, MASS, AND MOMENTUM
TRANSFER BETWEEN A HIGH
VELOCITY LIQUID JET AND A
CONCENTRIC GAS STREAM IN AN
AXISYMMETRIC CHANNEL

Prepared by:

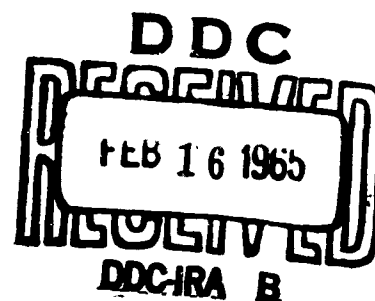
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for

U. S. Naval Underwater Ordnance Station
Newport, Rhode Island

under

Contract N140(122)76725B



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ABSTRACT

The purpose of this report is to present the results of the first phase of a detailed analytical study of the combined heat, mass, and momentum transfer processes that occur between a liquid stream and a concentric, higher velocity, annular gas stream when both the liquid stream and the annular gas stream are confined in an axisymmetric constant pressure, converging channel or an axisymmetric constant area, variable pressure channel.

The study began with an effort to determine whether the liquid stream entering the mixing section of an ejector-like device remained intact in a jet or atomized. The conclusions were that for the range of variables of interest the probability was that there was no significant jet breakup. Possible entrainment of liquid by the concentric gas stream has been neglected at this time.

Having established an analytical model based on the assumption that the liquid stream remains intact, the basic equations were numerically solved for a variety of conditions. Using the axial distance required to condense the vapor from the concentric gas stream on to the liquid jet as a measure of performance, (the shorter the better), it was found that:

1. A constant pressure converging mixing section is more effective than a constant area mixing section.
2. Increasing the number of liquid jets (constant total jet flow area) shortened the mixing section.
3. Increasing the Mach number of the gas stream at the mixing section inlet shortened the mixing section.
4. The amount of noncondensable present in the gas stream (from 20 to 50 percent by weight) did not significantly affect the distance required for condensation but did affect the shape of the mixing section.

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NOMENCLATURE

A	cross sectional flow area
C_d	nozzle discharge coefficient
C_D	drag coefficient for spherical drop
C_g	speed of sound in gas stream
C_p	specific heat at constant pressure
c_1, c_4	calculation constants
c_2	number of liquid jets
D	diameter
D_e	equivalent diameter for gas flow
D_g	diameter of mixing section
D'	binary diffusion coefficient
E	calculation constant
f	Fanning friction factor
F, F'	shear force from friction or momentum exchange
g_o	conversion factor, $32.174 \text{ lbm-ft/lbf-sec}^2$
g'	conversion factor, $4.17 \times 10^8 \text{ lbm-ft/lbf-hr}^2$
h	enthalpy
h_G	heat transfer coefficient from bulk gas to gas-liquid jet interface
h_L	heat transfer coefficient from gas-liquid jet interface to bulk liquid
J	conversion factor, $778.26 \text{ ft-lbf/Btu}$
k	thermal conductivity
K_g	ratio of specific heats of bulk gas mixture
K_G	mass transfer coefficient
L	mixing section or liquid jet length
W	molecular weight
M	Mach number
Pr	Prandtl number
P'_{nc}	log mean noncondensable partial pressure difference between the bulk gas mixture and the gas-liquid jet interface

p	static pressure in mixing section
q	heat flux
Q	total heat transfer from bulk gas to bulk liquid
r	radius
Re	Reynolds number
R_g	gas constant
R'	universal gas constant
s	entropy
Sc	Schmidt number
S_i, S_{ic}	surface area at phase interface
S'	Sutherland constant (see Appendix F)
t	thickness of annular gas nozzle at mixing section inlet plane
t^*	property calculation parameter (see Appendix F)
U	overall heat transfer coefficient
v	specific volume
V	velocity
V'	relative velocity
w	mass flow rate
We	Weber number
X	flowing mass quality of two-phase mixture
X_v	mole fraction of vapor in gas mixture
Z	ratio of Weber number to Reynolds number

Greek Letters

α	property calculation parameter (see Appendix F)
β	half-angle of mixing section divergence
γ	half-angle of liquid jet divergence
Δ	difference
$\epsilon_1 - \epsilon_6$	calculation constants
ϵ/k	molecular potential well depth
λ	wavelength of liquid jet disturbances

μ	viscosity
ρ	mass density
σ	molecular collision diameter
σ'	surface tension
τ	shear stress from friction or momentum exchange
ϕ	mass flow rate ratio of vapor to gas mixture
ω	mass flow rate ratio of liquid phase to gas phase
ω_{vol}	volumetric flow rate ratio of liquid phase to gas phase

Subscripts

o	refers to stagnation state
1	refers to mixing section inlet state or the initial state of each increment of mixing section length
2	refers to the end state of each increment of mixing section length
12	refers to total increment of mixing section length between states 1 and 2
b	refers to liquid jet breakup
c	refers to condensate from condensation of vapor
d	refers to liquid drops
f	refers to saturated liquid state
fg	refers to changes of state in vaporization
F	refers to final liquid drop conditions
g	refers to saturated vapor state or to condensable plus noncondensable gas mixture
i	refers to gas-liquid interface
I	refers to initial liquid drop conditions
j	refers to liquid jet
L	refers to liquid phase or liquid jet
m	refers to momentum exchange
nc	refers to noncondensable gas component

p	refers to constant pressure process
r	refers to relative value between gas and liquid phases
sat	refers to saturation condition
v	refers to condensable vapor component
w	refers to mixing section wall

Quantity over Symbol

—	signifies average value
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INTRODUCTION

General:

The purpose of this report is to present the analysis and results of our study of the combined heat, mass, and momentum transfer processes that occur between a liquid jet and a concentric, higher velocity, annular gas stream when both the jet and annular gas stream are confined in an axisymmetric channel. This particular investigation was undertaken as part of our continuing program in the fundamental study of ejector processes for the Naval Underwater Ordnance Station, Newport, Rhode Island.

Generally speaking, most ejector type devices are today designed by a combination of empirical data and one-dimensional thermodynamic equilibrium analyses. The results of such an approach have been satisfactory in most applications. However, when two-phase, two-component flow is involved, e.g., a liquid water jet and a concentric water vapor-carbon dioxide gas mixture, this traditional approach has not yielded devices of high performance nor has it predicted or explained all of the phenomena actually observed. Apparently, the addition of a non-condensable gaseous component and the resulting diffusion processes changes significantly the heat and momentum transfer processes in the system.

If one examines the schematic diagram in Figure 1, one can see that the ejector devices under consideration here have three regions of interest; the nozzles, the mixing section and the diffuser. The nozzle processes are well understood and nozzle performance can generally be accurately predicted (exceptions are flashing flow in the liquid nozzle and condensing flow in the gas mixture nozzle).

We chose to begin our study with the diffuser section of the ejector and Reference 6 presents our initial attempt to explain some of the experimental data presented in Reference 3. The results of this

early analytical study, even though one-dimensional and without consideration of rate processes, indicated that the only way one could rationalize the experimental data was to assume that the two-phase, two-component flow entering the diffuser section was not at thermodynamic equilibrium; i.e., the gas and liquid components were at different bulk temperature levels and that the two phases were flowing at different average velocities. The next step was to try to predict the diffuser section inlet conditions and hence our present study of what could be the mixing section process.

Jet Breakup and Atomization:

Our study of the mixing section process began by trying to establish an analytical model of the processes involved. Of major importance was the question of whether the liquid jet entering the mixing section remained a solid jet or atomized. Appendix A of this report contains the details of our study of the literature on atomization and jet breakup. The results of this study of the jet breakup and atomization literature indicated that there was a good probability that the liquid jet did not break up to any significant extent. (Neither the entrainment of the liquid nor the waviness of the liquid jet caused by the scrubbing action of the gas flow has been considered at this time.) In addition, visual results in Reference 16 also report no significant jet breakup. Thus, as a starting point, we have assumed the liquid jet does not break up.

This conclusion and the choice of our first analytical model have been reached on the basis of a limited amount of information, for in spite of the large amount of work in existence on atomization (7-13)* and turbulent jets (15, 16), little significant quantitative data on the behavior

* Numbers in parentheses refer to references.

of a high velocity liquid jet surrounded by a higher velocity axisymmetric annular gas stream was found. Therefore, one of the major recommendations of this study proposes to fill the gap in our knowledge of these fundamental processes of jet breakup and atomization by further study in this area.

Mixing Section Analytical Models:

Along with the derivations of the conservation equations, Appendices B through E of this report present the details of the computational procedures for the three analytical models considered herein. All analytical models considered thus far assume that the liquid jet remains intact with no liquid entrainment by the concentric annular gas stream and no liquid jet surface area increase due to waves on the liquid jet surface. Table I presents a summary of the three mixing section analytical models and indicates the differences between the models while Table II summarizes the assumptions common to each of the mixing section analyses. Table III is a summary of the input data and range of variables for which computations were carried out*. In addition to the detailed analyses, derivations, and computational procedures presented in Appendices B through E, certain auxiliary information, such as data sources, correlation sources, etc., are presented in Appendices F and G.

Method of Solution:

Generally speaking, the method of solution for each analytical model is to simultaneously solve the conservation equations of mass, momentum, and energy for the combined heat, mass, and momentum

* Because of space limitations, all calculated results are not presented herein.

transfer processes between the liquid jet and the concentric annular gas stream. The actual computational procedure employed in each analytical model is different due to the differences in the models. However, the numerical technique employed in each case involves a trial and error iterative procedure. The mixing section is divided into a number of intervals so that difference type equations are involved. In each interval of mixing section of each case, the solution is built around the initial estimate of a bulk gas-liquid jet interface temperature and successively improving the initial guess until all rate processes and conservation laws for each interval are satisfied.

The iterative technique referred to above is an extension of the method presented in References 17, 18 and 19. The only significant difference between the work referred to above and that presented herein is that changes in kinetic energy of either the gas or liquid stream have been included as significant in calculating total heat transfers. This modification of the earlier results was necessary because of the high relative velocities encountered in some of the cases considered below.

At present, the analytical models herein are restricted to use of input data for which the condensable vapor state at the mixing section inlet plane is approximately a saturated vapor state.

TABLE I**SUMMARY OF MIXING SECTION ANALYTICAL MODELS****Analytical Model I:**

1. constant pressure mixing section
2. no noncondensable gas in gas stream (gas stream completely condensable)

Analytical Model IIa:

1. constant pressure mixing section
2. condensable vapor and noncondensable gas present in gas stream

Analytical Model IIb:

1. differs from Analytical Model IIa in that a simplified relative velocity is assumed between concentric streams

Analytical Model III:

1. constant area mixing section
2. condensable vapor and noncondensable gas present in gas stream

TABLE II**SUMMARY OF ASSUMPTIONS COMMON TO ALL MIXING
SECTION ANALYSES**

1. The flow is steady.
2. The flow is one-dimensional.
3. The liquid is incompressible.
4. The ejector processes are adiabatic.
5. Height changes are negligible.
6. Surface tension effects are negligible.
7. There is no shaft work.
8. The liquid jet remains intact.
9. There is no entrainment of liquid in the gas stream.
10. The liquid and gas streams are concentric with the gas flow being annular.
11. The vapor enters the mixing section in a saturated or nearly saturated state.

TABLE III

SUMMARY OF REQUIRED INPUT DATA AND RANGE OF
INPUT DATA USED IN MIXING SECTION COMPUTATIONS

Property and Calculation Constants	Analytical Model		
	I	IIa and IIb	III
Liquid nozzle discharge coefficient, C_{dL}	0.98	0.98	0.98
Gas nozzle discharge coefficient, C_{dg}	0.98	0.98	0.98
Condensable molecular weight, W_v	18.016	18.016	18.016
Noncondensable molecular weight, W_{nc}	--	44.011	44.011
Universal gas constant, R'	1.9857	1.9857	1.9857
Condensable molecular collision diameter, σ_v	2.649	2.649	2.649
Noncondensable molecular collision diameter, σ_{nc}	--	3.996	3.996
Condensable molecular potential well depth, $(\epsilon/k)_v$	356.0	356.0	356.0
Noncondensable molecular potential well depth, $(\epsilon/k)_{nc}$	--	213.0	213.0
Property calculation parameter, α	--	0.265×10^{-23}	0.265×10^{-23}
Property calculation parameter, t^*	--	1.2	1.2
Condensable Sutherland constant, S'_v	--	559.74	559.74
Noncondensable Sutherland constant, S'_{nc}	--	233.0	233.0
Liquid density, ρ_L	64.0	64.0	64.0
Liquid thermal conductivity, k_L	0.354	0.354	0.354
Liquid specific heat, C_{pL}	1.	1.	1.
Conversion factor, g_o	32.174	32.174	32.174

Table III - continued

	I	IIa and IIb	III
Conversion factor, g'	4.17×10^8	4.17×10^8	4.17×10^8
Conversion factor, J	778.26	778.26	778.26
Bulk gas temperature decrement, ΔT_g	10.	0.25	0.25
Calculation constant, c_1	1.	1.5	1.5
Number of liquid jets, c_2	1.	1. ⁺ , 2., 4. ⁺ , 6., 8.	1., 4.
Fraction of total vapor condensed in each interval of mixing section, c_4	0.1	--	--
Calculation constant, ϵ_1	--	0.0001	0.0001
Calculation constant, ϵ_2	0.0001	20.	20.
Calculation constant, ϵ_3	--	0.999	0.999
Calculation constant, ϵ_4	--	5.	5.
Calculation constant, ϵ_6	--	2.	2.

⁺ Data used for Analytical Model IIb only.

Table III - continued

Data for Each Case*	I	IIa and IIb	III
Noncondensable flow rate, w_{nc} lbm/hr	--	151.2 ⁺ , 186.24, 279.36, 372.48, 456.6	151.2
Mixing section inlet Mach number, M_1	--	--	0.286
Ratio of total static pressure in mixing section to gas stagnation pressure at ejector inlet, p/p_{go}	0.834	0.953 ⁺ , 0.9, 0.8182, 0.72	--
Ejector inlet stagnation temperature ratio, T_{go}/T_{Lo}	7.08	8.5 ⁺ , 12.5	8.5
Gas stagnation pressure at ejector inlet, p_{go} psia	36.	94.5 ⁺ , 100. 110., 125.	94.5
Ejector inlet stagnation pressure ratio, P_{Lo}/P_{go}	8.75	3.44 ⁺ , 3.25, 2.955, 2.60	3.44
Gas stagnation temperature at ejector inlet, T_{go} F	283.	340. ⁺ , 500.	340.
Liquid nozzle exit diameter, D_{L1} in	0.295	0.295 ⁺ , 0.2086, 0.1475 ⁺ , 0.1204, 0.1043	0.295, 0.1475
Condensable flow rate at ejector inlet, w_{vo} lbm/hr	1410.	780. ⁺ , 744.76, 651.84, 588.72, 465.6	780.

* Data combinations used given on appropriate Figures.

+ Data used for Analytical Model IIb only.

RESULTS

Jet Breakup and Atomization:

The calculated results shown in Figures 2 through 6 compare the predictions of a variety of jet breakup and atomization correlations for a range of possible operating conditions. A more detailed discussion of these results and the correlations from which they were obtained is given in Appendix A.

Mixing Section Analyses:

1. Constant Pressure Mixing Section, No Noncondensable (Model I):

Figures 7 through 10 show some of the calculated results for one set of input data to analytical Model I plotted versus distance from the mixing section inlet plane. The figures are generally self-explanatory and show how various temperatures (Figure 7), various velocities (Figure 8), various Reynolds numbers (Figure 9), various heat transfer coefficients (Figure 9), and the liquid jet diameter and mixing section diameter (Figure 10) vary with distance along the mixing section. The percent of total inlet vapor flow condensed versus the distance from mixing section inlet plane is shown in Figure 26.

2. Constant Pressure Mixing Section, with Noncondensable (Models IIa and IIb):

Figures 11 through 14 show some of the calculated results for one set of input data to Analytical Model IIa, plotted with distance from mixing section inlet plane as the abscissa. The figures are generally self-explanatory and show how various temperatures (Figure 11), various velocities (Figure 12), various Reynolds numbers (Figure 13), various heat transfer coefficients (Figure 13), the mass transfer coefficient (Figure 13), and the liquid jet diameter and mixing section diameter (Figure 14) vary with distance along the mixing section.

Figures 15 through 18 show the results calculated from Analytical Model IIb for the same set of input data used in Analytical Model IIa. These figures are comparable to Figures 11 through 14, and show the differences resulting from the assumption of a simplified relative velocity between phases in the mixing section.

The percent of total inlet vapor flow condensed versus the distance from mixing section inlet plane is shown in Figure 26 for Models IIa and IIb. Also, for Model IIa the percent of total inlet vapor flow condensed versus the distance from mixing section inlet plane is shown for various inlet Mach numbers (Figure 23), for various inlet flow rate ratios of vapor to total gas mixture (Figure 24), and for various numbers of liquid jets (Figure 25).

3. Constant Area Mixing, with Noncondensable (Model III):

Figures 19 through 22 show some of the calculated results for one set of input data to Analytical Model III plotted with distance from mixing section inlet plane as the abscissa. The figures are generally self-explanatory and show how various temperatures (Figure 19), various velocities (Figure 20), various Reynolds numbers (Figure 21), and the liquid jet diameter and mixing section diameter (Figure 22) vary with distance along the mixing section.

The percent of total inlet vapor flow condensed versus the distance from mixing section inlet plane is shown in Figure 26. Figure 22 shows how the total static pressure in the mixing section varies from the mixing section inlet plane.

Comparison of Mixing Section Analytical Results:

In Figures 23 through 26 we compare how the total percent of vapor condensed (based upon amount possible to condense) varies versus the axial distance from the mixing section inlet plane for a variety of conditions.

Figure 23 shows the effect of increasing the gas mixture mixing section inlet Mach number while Figure 24 shows the effect of increasing the amount of noncondensable in the inlet gas mixture. Figure 25 shows the effect of increasing the number of liquid jets (fixed total liquid flow) and Figure 26 shows the effect of changing the mixing section analytical model. Insofar as possible, in each of Figures 23 through 26 all the conditions are held constant. As before, each of the figures is self-explanatory.

The most effective set of operating conditions (using shortest distance required to achieve 90 percent condensation as a criterion of effectiveness) is Analytical Model IIb - constant pressure mixing section with a simplified relative velocity between phases. Unfortunately, this model for the relative velocity between phases is too optimistic - the relative velocity model used in Analytical Model IIa is more realistic and thus Analytical Model IIa with eight liquid jets is the most effective.

The results in Figure 25 show that for a given amount condensed, the distance required decreases as the number of liquid jets increases. We did not go beyond eight liquid jets at this time because our assumption of no significant atomization would not be valid.

Comparison of Figures 13 and 21 shows why a constant pressure mixing section is more effective than a constant area mixing section. The Reynolds numbers, and hence, the heat and mass transfer coefficients, have a higher average value in the constant pressure mixing section than in the constant area mixing section. This is because the constant pressure mixing section converges as condensation takes place and thus the average gas mixture velocity remains higher than in a constant area mixing section.

CONCLUSIONS

Jet Breakup and Atomization:

The major conclusions of the jet breakup and atomization study are that:

1. The mechanics of atomization of a liquid jet in a high velocity gas stream are not well understood.
2. The available correlations indicate that in the range of volumetric and mass flow rate ratios of liquid to gas under consideration in the condensuctor, the predicted liquid jet breakup lengths are large compared to the condensuctor mixing section length and the final mean drop sizes are of the same order of magnitude as the initial liquid jet diameter (secondary stream nozzle exit diameter).
3. The mixing process in the mixing section of the condensuctor most probably involves heat, mass, and momentum transfer from the gas phase to a liquid jet with no significant breakup or atomization of the liquid jet occurring.

Mixing Section:

The general conclusions of the mixing section study are that:

1. A constant pressure mixing section requires a shorter axial distance for condensation of an equal amount of vapor than does a constant area mixing section for identical mixing section inlet conditions.
2. Increasing the number of liquid jets with constant total liquid flow area and liquid inlet velocity in any mixing section, decreases the axial distance required for a given amount of condensation.

3. Increasing the ratio of noncondensable gas to condensable vapor for a constant total gas flow in the constant pressure mixing section, does not significantly affect the distance required to condense 90 percent of the vapor flow as long as the mixing section has proper profile.
4. Increasing the gas phase mixing section inlet Mach number in the constant pressure mixing section, decreases the axial distance required for condensation.

RECOMMENDATIONS

Jet Breakup and Atomization:

The principle recommendations are that a transparent mixing section be provided for future testing of the condensuctor to permit visible records of the mixing process to be obtained by means of high-speed photography. This will make it possible to verify available correlations on jet breakup or develop new ones.

Mixing Section:

It is recommended that the mixing section analytical study be continued in order to relax some of the restricting assumptions of the present analyses and to include the diffusing, or diverging, section of an ejector-like device as a continuation of the mixing section process.

Some specific recommendations are:

1. Allow for liquid entrainment in the annular gas stream to determine if two-phase flow compressibility effects are involved and to determine its effect on axial length required for condensation.
2. Allow for superheated vapor in the gas stream at the mixing section inlet in order to extend the range of variables over which the analysis may be used.
3. Cut off the mixing section at some point, say 90 percent of allowable condensation completed, and add a diffuser section via a transition section in order to have a complete ejector analysis.
4. Fix a mixing section and diffuser geometry based on some desired design point and then use the fixed geometry to examine off-design operation.

APPENDIX A

LIQUID JET ATOMIZATION AND BREAKUP

Introduction:

This Appendix is concerned with an investigation of the possible mechanics of the mixing processes occurring in the mixing section and methods of predicting the degree of liquid jet breakup and atomization. In order to establish an analytical model for a theoretical study of the combined heat, mass, and momentum transfer between the two concentric streams entering the mixing section, one must be able to predict the length of the liquid jet at breakup and the mean liquid drop sizes resulting from the disintegration of the liquid jet.

A review of the literature on atomization and liquid jet breakup was made to determine the factors which affect the atomization of a high velocity liquid jet in a higher velocity concentric gas stream. The available correlations for liquid jet breakup and atomization thus found were used to predict liquid jet breakup length and final mean drop sizes over the range of variables of the NUOS condensuctor experimental test runs (Reference 3).

Review of Literature:

Beginning with Lord Rayleigh's study of jet instability in 1868, the phenomenon of liquid jet disintegration has been the subject of numerous theoretical and experimental investigations. Unfortunately, most of these investigations have been concerned with liquid jets discharging into a vacuum or into ambient atmosphere. Almost no work has been done with liquid jets being disintegrated by means of high velocity concentric gas streams.

Miesse (11) points out that the theoretical and experimental analyses of jet disintegration that have been made can all be grouped into three general classes, or into a combination of these classes. They are:

"1) Small Disturbance Method. An arbitrary small disturbance is imposed upon the surface of a liquid jet of given properties, and the effect of this disturbance is studied analytically by consideration of the well established physical conservation laws. -----Because the phenomena considered are, by nature, nonlinear, the mathematical solution of the problem can, in most cases, be effected only by employing the linearizing assumptions of the method of small perturbations. -----An obvious consequence of the use of this assumption is that the solution obtained is no longer (rigorously) valid when the magnitude of the growing disturbance exceeds a small percentage --- of the jet radius.

"2) Method of Plausible Conjectures. For the phenomena of secondary atomization, which occur subsequent to the initial growth of the disturbance, mathematical solutions can be obtained only by making plausible conjectures regarding the mechanism of the governing process. The validity of these conjectures can be substantiated only by the degree to which they effect correlation of the pertinent experimental data.

"3) Method of Dimensional Analysis. As the complex combinations of physical processes which occur in the disintegration of a liquid jet generally defy rigorous mathematical analysis, the pertinent experimental data can frequently be correlated effectively by consideration of the dimensionless groups of physical variables which have an effect on the physical process."

The small disturbance method has been used to study jet instability, wave formation, and jet breakup by Rayleigh, Tyler, Weber, Taylor, and recently by Morrell (12). This method has also been employed by Lane, Hinze, and Isshiki (8) to predict the breakup of liquid drops. A classic example of the method of plausible conjecture is that of Castleman (13), who utilized Rayleigh's theory of jet breakup to postulate ligament formation as an intermediate step to drop formation. Noting that liquid droplets

seemed to be torn directly from the main body of the liquid jet, he showed that the life period of a liquid filament from which the drops formed is in the order of magnitude of 10^{-5} seconds. Although Castleman was unable to see these filaments, recent high speed photographic techniques have permitted other investigators to prove their existence. The method of dimensional analysis to correlate experimental data has been used by the majority of investigators.

In particular, Ohnesorge (as described by Marshall (7)) correlated the experimental data of Hanlein by plotting the Z-number (ratio of Weber number to Reynolds number of the liquid jet) versus the Reynolds number of the liquid jet on a log-log chart. From this correlation he classified the modes of jet disintegration in four groups according to the rapidity of drop formation as follows:

"1) Slow dripping from an orifice without jet formation.

"2) Rayleigh mechanism of jet breakup wherein an axially symmetric disturbance produces breakup. The term varicose has been applied to these disturbances.

"3) Breakup caused by disturbances which are symmetrical about a helical axis starting at the orifice, as treated by Hanlein and Weber. These disturbances are sometimes referred to as sinuous.

"4) So-called atomization of the jet."

"Since for a given liquid and orifice size the Z-number is constant, a variation with the Reynolds number on the chart follows a horizontal line. Thus, at low Reynolds number, Zone I, the mode of breakup follows the Rayleigh mechanism and as the Reynolds number increases the mode passes into Zone II, where breakup follows a lateral motion with increasing amplitude, and the jet has a twisted or sinuous appearance. This is a narrow region, and there is a sharp transition from this zone to the zone of atomization at the orifice, Zone III."

It is interesting to note here that this correlation is based on a liquid jet in ambient atmosphere. If the liquid jet is subjected to a high velocity gas stream, the momentum transfer from the gas phase to the liquid phase tends to accelerate the jet as it progresses through the gas. Also, acceleration of the jet tends to stabilize it, decreasing the amplitude of its surface disturbances and keeping it intact.*

The physical properties affecting jet disintegration are:

1. liquid nozzle diameter, D_{L1}
2. liquid jet velocity, V_{L1}
3. relative velocity between gas and liquid, V_{r1}
4. liquid density, ρ_L
5. liquid viscosity, μ_L
6. surface tension, σ'
7. gas density, ρ_g
8. gas viscosity, μ_g
9. geometry of mixing chamber, D_g

Dimensionless quantities considered in various analyses are:

1. Reynolds number, Re
2. Weber number, We
3. Z-number, $Z = We/Re$
4. density ratio of gas to liquid, ρ_g/ρ_L
5. viscosity ratio of gas to liquid, μ_g/μ_L
6. ratio of wavelength of disturbances to nozzle diameter, λ/D_{L1}
7. ratio of breakup length to nozzle diameter, L_b/D_{L1}
8. ratio of final mean drop diameter to nozzle diameter, D_{dF}/D_{L1}
9. mass flow rate ratio of liquid to gas, ω
10. volumetric flow rate ratio of liquid to gas, ω_{vol}

* See series of photographs in recent EOS Report on jet condensers (16).

Experimental evidence indicates that the atomization of a liquid jet by means of a high velocity gas stream is a threefold process characterized by the following distinct phases:

1. The liquid jet undergoes surface deformations which cause the jet to break up when the amplitude of the deformations become sufficiently large.
2. Liquid filaments are detached from the main mass of the jet. These filaments are unstable and extremely short-lived (on the order of 10^{-5} seconds) and immediately form drops.
3. These initial drops are subjected to surface deformation and are eventually broken down into successively smaller drops.

Nukiyama and Tanasawa (7) and Isshiki (8) have investigated liquid jet breakup and liquid droplet deformation, respectively. Nukiyama and Tanasawa developed equation A9 to predict the final volume-surface mean drop size for the overall process of atomization. Isshiki derived a semi-empirical expression, equation A13, to correlate the initial and final drop size for the third phase of the atomization process.

Both of these investigators include liquid to gas flow rate ratio terms in their correlations thereby accounting for a finite gas medium and the transfer of momentum from the gas to the liquid phase.

Calculated Parameters:

Liquid jet Reynolds number

$$(Re)_j = \frac{V_{L1} D_{L1} \rho_L}{\mu_L} \quad (A1)$$

Liquid jet Weber number

$$(We)_j = V_{L1} / \left(\frac{\rho_L D_{L1}}{\sigma'} \right)^{1/2} \quad (A2)$$

Liquid jet Z-number

$$Z = (We)_j / (Re)_j \quad (A3)$$

Liquid drop Reynolds number

$$(Re)_{dI} = \frac{\rho_L V_{rl} D_{dI}^*}{\mu_L} \quad (A4)$$

Liquid drop Weber number

$$(We)_{dI} = \frac{\rho_g V_{rl}^2 r_{dI}^*}{\sigma'} \quad (A5)$$

Liquid jet breakup length

$$**(11) \quad L_b = 94.4 D_{L1} \left[\frac{V_{L1}^3}{r_{L1}} \left(\frac{\rho_L}{\sigma'} \right)^4 \left(\frac{\mu_g}{\rho_g} \right)^5 \right]^{1/8} \quad (A6)$$

$$(7) \quad L_b = \pi \sqrt{2} D_{L1} \left(1 + \frac{3 \mu_L}{(\rho_L \sigma' D_{L1})^{1/2}} \right)^{1/2} \quad (A7)$$

$$(12) \quad L_b = 2 D_{L1} \left(\frac{\rho_L}{\rho_g} \right)^{1/2} \quad (A8)$$

* Initial drop radii $\begin{cases} (r_{dI})_{\max} = r_{L1} \\ (r_{dI})_{\min} = 6.5 \sigma' / (\rho_g V_{rl}^2) \end{cases}$

** numbers in parentheses refer to references.

Final mean drop radius

$$(7) \bar{r}_{dF} = \frac{1}{2} \left[\frac{1410.}{V_{rL}} \left(\frac{\sigma'}{\rho_L} \right)^{0.5} + 191 \left(\frac{\mu_L}{\sqrt{\sigma' \rho_L}} \right)^{0.45} (1000 \omega_{vol})^{1.5} \right] \quad (A9)$$

$$(7) \bar{r}_{dF} = 1.1 \times 10^6 V_{r1}^{-1.68} D_{L1} \quad (A10)$$

$$(10) \bar{r}_{dF} = 91,500. \left(\frac{w_L}{\rho_L} \right)^{\frac{1}{12}} V_{r1}^{-4/3} \quad (A11)$$

$$(11) \bar{r}_{dF} = r_{L1} \left(\frac{\sigma'}{2 \rho_L r_{L1} V_{r1}} \right)^{1/3} \left[23.5 + 0.000395 \left(\frac{2 \rho_L r_{L1} V_{r1}}{\mu_L} \right) \right] \quad (A12)$$

$$(8) \left(\frac{\bar{r}_{dF}}{r_{dI}} \right)^{0.25} = \frac{1.6}{(We)_{dI}^{0.25}} + \frac{3}{2} \left(\frac{\rho_g}{\rho_L} \right)^{0.5} (1+\omega) C_{DI}$$

$$\left(\ln \frac{r_{dI}}{\bar{r}_{dF}} \right)^{0.25} (We)_{dI}^{0.125} \quad (A13)$$

Results:

The correlations given in equations A1-A13 were used to calculate liquid jet breakup length and final mean drop radius for two selected experimental test runs. Run No. 1 represents a typical noncondensable flow case, i.e., the gas phase consists of a mixture of water vapor and noncondensable CO₂ gas; Run No. 2 represents a typical condensable flow case with the gas phase consisting entirely of water vapor. Test data for the two cases is listed in Table IV while the calculated parameters are given in Table V.

A computer program was developed to perform the calculations and is set up to perform calculations based on a given set of condensor inlet conditions, nozzle exit diameters, as well as the static pressure at mixing section inlet. In order to investigate their effect upon the calculated parameters, three of these conditions may be varied for any remaining set of inlet conditions. These remaining variables are mass flow rate ratio, ω_1 , ratio of static pressure at mixing section inlet to gas stagnation pressure at ejector inlet, p_1/p_{go} , and ratio of liquid stagnation pressure to gas stagnation pressure at ejector inlet, p_{Lo}/p_{go} . This computer program will be useful in the future to compare calculated values of liquid jet breakup characteristics with experimental test results. Such a comparison can establish the accuracy of the available correlations or lead to more accurate ones.

Figures 2 and 3 show how liquid jet breakup length, L_b , varies with the static pressure at the mixing section inlet for a noncondensable flow case and a condensable flow case, respectively. The actual experimental test pressure is indicated in each figure. The correlations given by equations A6 and A8 show that the length of the liquid jet at breakup increases as the pressure at the mixing section inlet decreases. This is caused primarily by the decrease in gas density attending the drop in pressure. The resulting increase in relative velocity between the liquid and gas phases would seem to stabilize the liquid jet permitting greater lengths before breakup. The correlation given by equation A7 does not account for the effects of a high velocity gas stream surrounding the liquid jet, nor the initial liquid jet velocity. Equation A6 indicates that the liquid jet will be longer at breakup if the initial velocity of the liquid jet increases.

Figures 4 and 5 show how the ratio of final mean drop radius to initial jet radius, \bar{r}_{dF}/r_{L1} , varies with the mass flow rate ratio for a noncondensable flow case and a condensable flow case, respectively. The

actual test value of mass flow rate ratio is indicated in each figure. The results of four correlations given by equations A9, A10, A11 and A12 are shown in each figure. Because of the observed transitional nature of jet breakup and atomization, it is highly unlikely that atomization occurs at radius ratios, \bar{r}_{dF}/r_{L1} , equal to or greater than 1.0. The range of results is large with equation A9 giving a fair average of the other correlations. Equations A9 and A11 indicate that the radius ratio, \bar{r}_{dF}/r_{L1} , increases as the mass flow rate ratio, ω , increases. This trend agrees with the results obtained from the correlations on liquid jet breakup length in that higher initial liquid jet velocity tends to postpone jet breakup and droplet formation. Equations A10 and A12 plot as straight lines in the figures with values from equation A12 being approximately 100 times greater than those from equation A10.

Figure 6 shows how the ratio of final mean drop radius to initial jet radius, \bar{r}_{dF}/r_{L1} , calculated from equation A9 varies with volumetric flow rate ratio of liquid phase to gas phase, ω_{vol} . Three points are indicated for each flow case at various values of static pressure at the mixing section inlet, p_1 . This plot indicates that the radius ratio, \bar{r}_{dF}/r_{L1} , increases as the volumetric flow rate ratio, ω_{vol} , increases.

Equation A13 may be used to calculate final mean drop radius if the initial drop radius at the beginning of liquid jet breakup is known. For purposes of these calculations, we have assumed that the initial drop radius may range between a maximum equal to the initial jet radius and a minimum based upon an assumed initial drop Weber number, $(We)_{dI}$, equal to 6.5. Table V lists the initial and final drop radii obtained for the two representative flow cases. In both cases the assumption of a minimum initial radius does not produce any change, whereas the assumption of a maximum initial radius produces a growth in drop size. Thus, the correlation of equation A13 predicts no droplet breakup if liquid jet breakup is assumed.

TABLE IV
SUMMARY OF SELECTED EXPERIMENTAL DATA USED
IN JET BREAKUP COMPUTATIONS

Run No.	w_L lbm/min	w_{vo} lbm/min	w_{nc} lbm/min	T_{go} F	T_{Lo} F	P_{go} psia	P_{Lo} psia	P_l psia	r_{Ll} in	t_l in	NUOS* Run No.
1	323.	13.0	2.52	340.	40.	94.5	325.	90.	0.147	0.651	A3-C2H
2	358.	23.5	0.	283.	40.	36.0	315.	30.	0.147	0.651	A3-3A

* U. S. Naval Underwater Ordnance Station (References 3 and 4).

TABLE V
SUMMARY OF CALCULATED RESULTS FOR JET BREAKUP

Run No.	ω	ω vol	τ_{gl} F	V_{gl} ft/sec	V_{L1} ft/sec	V_{r1} ft/sec	$(Re)_g$ $\times 10^6$	$(Re)_j$ $\times 10^6$	$(We)_j$ $\times 10^5$	Z
1	20.81	0.0687	331.1	442.1	184.5	257.6	0.259	0.278	0.578	0.208
2	15.23	0.0173	251.9	844.7	203.1	641.5	0.170	0.306	0.637	0.208

Run No.	Eqn. A6		Eqn. A7		Eqn. A8		Eq. A9	Eq. A10	Eq. A11	Eq. A12	Eqn. A13			
	L_b	L_b/D_{L1}	L_b	L_b/D_{L1}	L_b	L_b/D_{L1}	\bar{r}_{dF} in	\bar{r}_{dF} in	\bar{r}_{dF} in	\bar{r}_{dF} in	$(r_{dI})_{min}$ in	$(r_{dI})_{max}$ in	$(\bar{r}_{dF})_{min}$ in	$(\bar{r}_{dF})_{max}$ in
1	12.6	42.8	1.3	4.5	10.3	34.8	0.381	0.0048	0.0030	0.0359	0.001	0.147	0.001	21.4
2	25.5	86.5	1.3	4.5	17.5	59.4	0.048	0.0010	0.0009	0.0353	0.0005	0.147	0.0005	0.555

APPENDIX B

CONSTANT PRESSURE MIXING WITH NO NONCONDENSABLE
(ANALYTICAL MODEL I)

Computational Procedure:

We begin by calculating the following quantities at the ejector inlet stagnation state (state o) and at the entrance to the mixing section (state 1).

$$\text{STATE} = 1. \quad (\text{B1})$$

$$T_{Lo} = T_{go} / (T_{go} / T_{Lo}) \quad (\text{B2})$$

$$T_{L1} = T_{Lo} \quad (\text{B3})$$

$$p_{Lo} = p_{go} (p_{Lo} / p_{go}) \quad (\text{B4})$$

$$p = p_{go} (p / p_{go}) \quad (\text{B5})$$

$$\phi_o = 1. \quad (\text{B6})$$

$$w_{v1} = w_{vo} \quad (\text{B7})$$

$$w_{c1} = 0. \quad (\text{B8})$$

$$\phi_1 = \phi_o \quad (\text{B9})$$

$$w_{go} = w_{vo} \quad (\text{B10})$$

$$w_{g1} = w_{go} \quad (\text{B11})$$

$$A_{L1} = c_2 (\pi D_{L1}^2 / 4.) \quad (\text{B12})$$

$$V_{L1} = C_{dL} \left(\frac{288. g_o (p_{Lo} - p)}{\rho_L} \right)^{1/2} \quad (\text{B13})$$

$$w_L = 3600. \rho_L V_{L1} A_{L1} / 144. \quad (\text{B14})$$

$$T_{go}(R)^* = T_{go} + 459.69 \quad (\text{B15})$$

$$T_{go}(K) = 5. T_{go}(R) / 9. \quad (\text{B16})$$

* All temperatures are in degrees F except as indicated by (R) or (K) which refer to the Rankine and Kelvin temperature scales, respectively.

Call SATT** (p, T_{go} , T_{sat})

$$T_{sat\ 1} = T_{sat} \quad (B17)$$

Call VAPTP (T_{go} , p_{go} , h_{go} , s_{go} , v_{go})

$$s_{g1} = s_{go} \quad (B18)$$

Call VAPTP (T_{sat} , p, h_g , s_g , v_g)

If ($s_{g1} - s_g$) B21, B19, B26

$$T_{g1} = T_{sat} \quad (B19)$$

$$h_{g1} = h_g \quad (B20)$$

go to B27

$$T_{g1} = T_{sat} \quad (B21)$$

Call SATLQ (T_{g1} , v_f , s_f , h_f)

$$s_{fg} = s_g - s_f \quad (B22)$$

$$h_{fg} = h_g - h_f \quad (B23)$$

$$X = (s_{g1} - s_f) / s_{fg} \quad (B24)$$

$$h_{g1} = h_f + X h_{fg} \quad (B25)$$

go to B27

Call SUPHT1 ($T_{sat\ 1}$, p, s_g , T_{g1}) (B26)

Call VAPTP (T_{g1} , p, h_{g1} , s_{g1} , v_{g1})

$$V_{g1} = C_{dg} (2. g_o J (h_{go} - h_{g1}))^{1/2} \quad (B27)$$

$$h_{g1} = h_{go} - C_{dg}^2 (h_{go} - h_{g1}) \quad (B28)$$

If ($h_{g1} - h_g$) B29, B29, B37

$$T_{g1} = T_{sat} \quad (B29)$$

$$T_{g1}(R) = T_{g1} + 459.69 \quad (B30)$$

$$T_{g1}(K) = 5. T_{g1}(R)/9. \quad (B31)$$

$$X = (h_{g1} - h_f)/h_{fg} \quad (B32)$$

$$w_{v1} = X w_{vo} \quad (B33)$$

$$w_{c1} = w_{vo} (1. - X) \quad (B34)$$

$$w_{g1} = w_{v1} \quad (B35)$$

$$T_{L1} = T_{L1} + \frac{w_{c1} \left(C_{pL} (T_{g1} - T_{L1}) + \frac{V_{g1}^2 - V_{L1}^2}{2 \cdot g_o J} \right)}{C_{pL} w_L} \quad (B36)$$

go to B40

$$\text{Call SUPHT2 } (T_{sat 1}, p, h_{g1}, T_{g1}) \quad (B37)$$

$$T_{g1}(R) = T_{g1} + 459.69 \quad (B38)$$

$$T_{g1}(K) = 5. T_{g1}(R)/9. \quad (B39)$$

$$\text{Call VAP } (T_{g1}, T_{g1}(K), p, (\epsilon/k)_v, W_v, \sigma_v, J, \rho_{g1}, \mu_{g1}, k_{g1}, C_{pg1}) \quad (B40)$$

$$C_{pvl} = C_{pg1} \quad (B41)$$

$$A_{g1} = 144. w_{g1} / (3600. \rho_{g1} V_{g1}) \quad (B42)$$

$$D_{g1} = (4. (A_{g1} + A_{L1}) / \pi)^{1/2} \quad (B43)$$

$$\omega_1 = w_L / w_{g1} \quad (B44)$$

$$\omega_o = \omega_1 \quad (B45)$$

$$(w_c / S_i) = 0. \quad (B46)$$

$$L_1 = 0. \quad (B47)$$

$$S_{i1} = 0. \quad (B48)$$

$$Q_1 = 0. \quad (B49)$$

$$\text{phase velocity ratio} = V_{g1}/V_{L1} \quad (B50)$$

$$\text{bulk temperature ratio} = T_{g1}/T_{L1} \quad (B51)$$

$$(\text{Pr})_{g1} = C_{pg1} \mu_{g1}/k_{g1} \quad (B52)$$

$$\text{Call VISLIQ}(T_{L1}, \mu_{L1}) \quad (B53)$$

$$V_{r1} = |V_{g1} - V_{L1}| \quad (B54)$$

$$(\text{Pr})_{L1} = C_{pL} \mu_{L1}/k_L \quad (B55)$$

$$D_{e1} = 4. A_{g1}/(\pi(D_{g1} + c_2 D_{L1})) \quad (E56)$$

$$(\text{Re})_{g1} = 3600. \rho_{g1} V_{g1} D_{e1}/(12. \mu_{g1}) \quad (B57)$$

$$T_{i1} = T_{\text{sat}} \quad (B58)$$

$$T_{i1}(\text{R}) = T_{i1} + 459.69 \quad (B59)$$

$$T_{i1}(\text{K}) = 5. T_{i1}(\text{R})/9. \quad (B60)$$

$$\text{Call SATP}(T_{i1}, p_{c1})$$

$$\text{Call SATHFG}(T_{i1}, p_{c1}, h_{gcl}, h_{fcl})$$

$$h_{fgcl} = h_{gcl} - h_{fcl} \quad (B61)$$

$$\text{Call SATLQV}(T_{i1}, v_{c1})$$

$$\text{Call VISLIQ}(T_{i1}, \mu_{c1})$$

$$\rho_{c1} = 1./v_{c1} \quad (B62)$$

$$V'_{g1} = 0.75 V_{r1} \quad (B63)$$

$$V'_{L1} = 0.25 V_{r1} \quad (B64)$$

$$E = 0. \quad (B65)$$

$$(\text{Re})_{L1} = 3600. \rho_L V'_{L1} D_{L1}/(12. \mu_{L1}) \quad (B66)$$

$$(Re)_{rgl} = 3600. \rho_{gl} V'_{gl} D_{el} / (12. \mu_{gl}) \quad (B67)$$

If $((Re)_{L1} - 12,500.)$ B68, B68, B69

$$h_{L1} = 1.86 (12. k_L / D_{L1}) (Re)_{L1}^{1/3} (Pr)_{L1}^{1/3} (\mu_{L1} / \mu_{cl})^{0.14} \quad (B68)$$

go to B70

$$h_{L1} = 0.023 (12. k_L / D_{L1}) (Re)_{L1}^{0.8} (Pr)_{L1}^{0.4} \quad (B69)$$

Call CASP4 $(T_{il}(K), \sigma_v, (\epsilon/k)_v, W_v, \mu_{gil})$ (B70)

IF $((Re)_{rgl} - 9000.)$ B71, B71, B72

$$h_{G1} = 1.86 (12. k_{gl} / D_{el}) (Re)_{rgl}^{1/3} (Pr)_{gl}^{1/3} (\mu_{gl} / \mu_{gil})^{0.14} \quad (B71)$$

go to B73

$$h_{G1} = 0.027 (12. k_{gl} / D_{el}) (Re)_{rgl}^{0.8} (Pr)_{gl}^{1/3} (\mu_{gl} / \mu_{gil})^{0.14} \quad (B72)$$

If $((Re)_{rgl} - 1000.)$ B74, B74, B75 (B73)

$$f_i = 16. / (Re)_{rgl} \quad (B74)$$

go to B76

$$f_i = 0.0014 + (0.125 / (Re)_{rgl}^{0.32}) \quad (B75)$$

$$\tau_i = 3600. f_i \rho_{gl} V'_{gl}^2 / (2. g') \quad (B76)$$

$$(q_L / S_i)_1 = h_{L1} (T_{il} - T_{L1}) \quad (B77)$$

$$(w_c / S_i)_1 = \frac{(q_L / S_i)_1 - h_{G1} (T_{gl} - T_{il})}{h_{fgcl} + C_{pL} (T_{il} - T_{L1}) + \frac{V_{gl}^2 - V_{L1}^2}{2. g_o J}} \quad (B78)$$

$$\tau_m = 3600. (w_c / S_i)_1 V'_{gl} / g' \quad (B79)$$

$$\tau = \tau_i + \tau_m \quad (B80)$$

$$V'_{L1} = \left[\frac{\rho_{g1}}{\rho_L} \left(\frac{(Re)_{L1}}{(Re)_{rg1}} \right)^{0.2} V'_{g1} + \frac{2 \cdot \tau_m (Re)_{L1}^{0.2} g'}{(0.046) 3600 \cdot \rho_L} \right]^{1/2} \quad (B81)$$

$$V'_{g1} = V_{g1} - V_{L1} - V'_{L1} \quad (B82)$$

If (E-50.) B83, B83, B86

$$\text{If } \left(\left| \frac{(w_c/S_i)_1 - (w_c/S_i)}{(w_c/S_i)_1} \right| - \epsilon_2 \right) \text{ B86, B84, B84} \quad (B83)$$

$$(w_c/S_i) = (w_c/S_i)_1 \quad (B84)$$

$$E = E + 1. \quad (B85)$$

go to B66

$$(q_g/S_i)_1 = h_{G1}(T_{g1} - T_{i1}) + (w_c/S_i)_1 \left(h_{fgc1} + C_{pL}(T_{i1} - T_{L1}) + \frac{V_{g1}^2 - V_{L1}^2}{2 \cdot g_o J} \right) \quad (B86)$$

$$\Delta T_1 = T_{g1} - T_{L1} \quad (B87)$$

$$U_1 = (q_L/S_i)_1 / \Delta T_1 \quad (B88)$$

At this point we have calculated all variables at state 1. We now

commence our calculations for the first state 2.

$$c_3 = 0. \quad (B89)$$

$$\text{STATE} = \text{STATE} + 1. \quad (B90)$$

$$\Delta T_g = c_1 \Delta T_g \quad (B91)$$

$$T_{g2} = T_{g1} - \Delta T_g \quad (B92)$$

If $(T_{g2} - T_{sat})$ B93, B94, B94

$$T_{g2} = T_{sat} \quad (B93)$$

$$(w_c)_{12} = c_4 w_{vo} \quad (B94)$$

$$c_3 = c_3 + c_4 \quad (B95)$$

$$T_{g2}(R) = T_{g2} + 459.69 \quad (B96)$$

$$T_{g2}(K) = 5. T_{g2}(R)/9. \quad (B97)$$

If $(0.99 - c_3)$ B98, B98, B101

If $(1.399 - c_3)$ B100, B100, B99 (B98)

$$(w_c)_{12} = 0.02 w_{vo} \quad (B99)$$

go to B101

$$(w_c)_{12} = 0.01 w_{vo} \quad (B100)$$

$$w_{v2} = w_{v1} - (w_c)_{12} \quad (B101)$$

$$w_{g2} = w_{g1} - (w_c)_{12} \quad (B102)$$

$$T_{i2} = T_{sat} \quad (B103)$$

$$T_{i2}(R) = T_{i2} + 459.69 \quad (B104)$$

$$T_{i2}(K) = 5. T_{i2}(R)/9. \quad (B105)$$

Call SATP (T_{i2}, p_{c2})

Call SATHFG $(T_{i2}, p_{c2}, h_{gc2}, h_{fc2})$

$$h_{fgc2} = h_{gc2} - h_{fc2} \quad (B106)$$

$$w_{c2} = w_{c1} + (w_c)_{12} \quad (B107)$$

Call VAP $(T_{g2}, T_{g2}(K), p, (\epsilon/k)_v, W_v, \sigma_v, J, \rho_{g2}, \mu_{g2},$
 $k_{g2}, C_{pg2})$

$$C_{pv2} = C_{pg2} \quad (B108)$$

$$(Pr)_{g2} = C_{pg2} \mu_{g2} / k_{g2} \quad (B109)$$

$$\Delta h_v = C_{pv1} T_{g1}(R) - C_{pv2} T_{g2}(R) \quad (B110)$$

$$(q_v)_{12} = w_{v2} \Delta h_v \quad (B111)$$

$$V_{L2} = V_{L1} \quad (B112)$$

$$V_{g2} = V_{g1} \quad (B113)$$

$$V'_{g2} = V'_{g1} \quad (B114)$$

$$V'_{L2} = V'_{L1} \quad (B115)$$

$$T_{L2} = T_{L1} + \frac{(q_v)_{12} + (w_c)_{12} (h_{fgc1} + c_{pv2} (T_{g2} - T_{i1}))}{C_{pL} (w_L + w_{c1})} \quad (B116)$$

$$(S_i)_{12o} = 0. \quad (B117)$$

$$E = 0. \quad (B118)$$

$$(w_c/S_i)_2 = (w_c/S_i)_1 + 2. \quad (B119)$$

$$\text{Call SATLQV } (T_{i2}, v_{c2}) \quad (B120)$$

$$\text{Call VISLIQ } (T_{i2}, \mu_{c2})$$

$$\rho_{c2} = 1./v_{c2} \quad (B121)$$

$$\Delta \bar{T}_{gc} = (T_{g1} + T_{g2} - T_{i1} - T_{i2})/2 \quad (B122)$$

$$\Delta \bar{h}_{vc} = (C_{pv1} + C_{pv2}) \Delta \bar{T}_{gc} / 2. \quad (B123)$$

$$\bar{h}_{fgc} = (h_{fgc1} + h_{fgc2})/2. \quad (B124)$$

$$\Delta V_g = (V_{g1}^2 - V_{g2}^2)/(2 \cdot g_o J) \quad (B125)$$

$$\Delta V_L = (V_{L1}^2 - V_{L2}^2)/(2 \cdot g_o J) \quad (B126)$$

$$\Delta V_{gL} = (V_{g1}^2 - V_{L2}^2)/(2 \cdot g_o J) \quad (B127)$$

$$\Delta \bar{h}_{cL} = C_{pL} ((T_{i1} + T_{i2})/2. - T_{L2}) \quad (B128)$$

$$(q_v)_{12} = w_{v2} (\Delta h_v + \Delta V_g) \quad (B129)$$

$$(q_c)_{12} = (w_c)_{12} (\bar{h}_{fgc} + \Delta \bar{h}_{vc} + \Delta \bar{h}_{cL} + \Delta V_{gL}) \quad (B130)$$

$$(q_L)_{12} = (w_L + w_{c1}) \Delta v_L \quad (B131)$$

$$Q_{12} = (q_v)_{12} + (q_c)_{12} + (q_L)_{12} \quad (B132)$$

$$T_{L2} = T_{L1} + \frac{Q_{12}}{C_{pL} (w_L + w_{c1})} \quad (B133)$$

$$\Delta T_2 = T_{g2} - T_{L2} \quad (B134)$$

$$\Delta T_M = \frac{(T_{g1} - T_{L1}) - (T_{g2} - T_{L2})}{\ln \left(\frac{T_{g1} - T_{L1}}{T_{g2} - T_{L2}} \right)} \quad (B135)$$

$$\text{Call VISLIQ } (T_{L2}, \mu_{L2})$$

$$(Pr)_{12} = C_{pL} \mu_{L2} / k_L \quad (B136)$$

$$(w_c \bar{S}_i) = \frac{(w_c / S_i)_1 - (w_c / S_i)_2}{\ln \left(\frac{(w_c / S_i)_1}{(w_c / S_i)_2} \right)} \quad (B137)$$

$$(S_{ic})_{12} = (w_c)_{12} / (w_c \bar{S}_i) \quad (B138)$$

Sense Light 1

$$A_{g2} = 144. w_{g2} / (3600. \rho_{g2} V_{g2}) \quad (B139)$$

$$A_{L2} = 144. \left(\frac{w_L}{\rho_L V_{L2}} + \frac{w_{c2}}{\rho_{c2} V_{L2}} \right) / 3600. \quad (B140)$$

$$D_{L2} = (4. A_{L2} / (\pi c_2))^{1/2} \quad (B141)$$

$$D_{g2} = (4. (A_{g2} + A_{L2}) / \pi)^{1/2} \quad (B142)$$

$$\bar{D}_L = (D_{L1} + D_{L2}) / 2. \quad (B143)$$

$$\bar{D}_g = (D_{g1} + D_{g2}) / 2. \quad (B144)$$

$$D_{e2} = 4. A_{g2} / (\pi (D_{g2} + c_2 D_{L2})) \quad (B145)$$

$$V_{r2} = \left| V_{g2} - V_{L2} \right| \quad (B146)$$

$$L_{12} = \left[\left(\frac{12. (S_{ic})_{12}}{\pi c_2 \frac{D_{L2} + D_{L1}}{2.}} \right)^2 - \frac{D_{L2} - D_{L1}}{2.} \right]^{1/2} \quad (B147)$$

$$\bar{V}_g = (V_{g1} + V_{g2})/2. \quad (B148)$$

$$\bar{V}'_g = (V'_{g1} + V'_{g2})/2. \quad (B149)$$

$$\bar{V}_L = (V_{L1} + V_{L2})/2. \quad (B150)$$

$$(Re)_{g2} = 3600. \rho_{g2} V_{g2} D_{e2} / (12. \mu_{g2}) \quad (B151)$$

$$(Re)_{rg2} = 3600. \rho_{g2} V'_{g2} D_{e2} / (12. \mu_{g2}) \quad (B152)$$

$$\text{Call FORCE } (\bar{D}_L, \bar{D}_g, L_{12}, \bar{V}_g, \bar{V}'_g, (S_{ic})_{12}, (Re)_{g1}, (Re)_{g2},$$

$$(Re)_{rg1}, (Re)_{rg2}, \rho_{g1}, \rho_{g2}, g', F_i, F_w)$$

$$F_m = 3600. (w_c)_{12} \bar{V}'_g / g' \quad (B153)$$

$$\text{If } (\bar{V}_g - \bar{V}_L) \text{ B154, B155, B155}$$

$$F_i = - F_i \quad (B154)$$

$$F = F_m + F_i \quad (B155)$$

$$\tau = \left| F / (S_{ic})_{12} \right| \quad (B156)$$

$$\tau_m = 3600. (w_c / S_i)_{12} V'_{g2} / g' \quad (B157)$$

$$(Re)_{L2} = 3600. \rho_L V'_{L2} D_{L2} / (12. \mu_{L2}) \quad (B158)$$

$$F'_m = 3600. (w_c)_{12} (V'_{L1} + V'_{L2}) / (2. g') \quad (B159)$$

$$V_{L2} = \frac{3600. (w_L + w_{c1}) V_{L1} + g' (F + F'_m)}{3600. (w_L + w_{c2})} \quad (B160)$$

$$V_{g2} = \frac{3600. w_{g1} V_{g1} - g' (F + F_w)}{3600. w_{g2}} \quad (B161)$$

$$V'_{L2} = \left[\frac{\rho_{g2}}{\rho_L} \left(\frac{(Re)_{L2}}{(Re)_{rg2}} \right)^{0.2} V'_{g2}^2 + \frac{2 \cdot \tau_m (Re)_{L2}^{0.2} g'}{(0.046) 3600 \cdot \rho_L} \right]^{1/2} \quad (B162)$$

$$V'_{g2} = V_{g2} - V_{L2} - V'_{L2} \quad (B163)$$

If (Sense Light 1) B139, B164

$$\text{Call GASP4 } (T_{i2}(K), \sigma_v, (\epsilon/k)_v, W_v, \mu_{gi2}) \quad (B164)$$

If $((Re)_{rg2} - 9000.)$ B165, B165, B166

$$h_{G2} = 1.86 (12 \cdot k_{g2}/D_{e2}) (Re)_{rg2}^{1/3} (Pr)_{g2}^{1/3} (\mu_{g2}/\mu_{gi2})^{0.14} \quad (B165)$$

go to B166a

$$h_{G2} = 0.027 (12 \cdot k_{g2}/D_{e2}) (Re)_{rg2}^{0.8} (Pr)_{g2}^{1/3} (\mu_{g2}/\mu_{gi2})^{0.14} \quad (B166)$$

If $((Re)_{L2} - 12,500.)$ B167, B167, B168 (B166a)

$$h_{L2} = 1.86 (12 \cdot k_L/D_{L2}) (Re)_{L2}^{1/3} (Pr)_{L2}^{1/3} (\mu_{L2}/\mu_{c2})^{0.14} \quad (B167)$$

go to B169

$$h_{L2} = 0.023 (12 \cdot k_L/D_{L2}) (Re)_{L2}^{0.8} (Pr)_{L2}^{0.4} \quad (B168)$$

$$(q_L/S_{i2}) = h_{L2} (T_{i2} - T_{L2}) \quad (B169)$$

$$(w_c/S_{i2}) = \frac{(q_L/S_{i2}) - h_{G2} (T_{g2} - T_{i2})}{h_{fgc2} + C_{pL} (T_{i2} - T_{L2}) + \frac{V_{g2}^2 - V_{L2}^2}{2 \cdot g_o J}} \quad (B170)$$

$$(q_g/S_{i2}) = h_{G2} (T_{g2} - T_{i2}) + (w_c/S_{i2}) \left(h_{fgc2} + C_{pL} (T_{i2} - T_{L2}) + \frac{V_{g2}^2 - V_{L2}^2}{2 \cdot g_o J} \right) \quad (B171)$$

$$U_2 = (q_L/S_{i2}) / \Delta T_2 \quad (B172)$$

$$(\overline{w_c/S_i}) = \frac{(w_c/S_i)_1 - (w_c/S_i)_2}{\ln \left(\frac{(w_c/S_i)_1}{(w_c/S_i)_2} \right)} \quad (B173)$$

$$(S_i)_{12} = (w_c)_{12} / (\overline{w_c/S_i}) \quad (B174)$$

$$\overline{U} = Q_{12} / ((S_i)_{12} \Delta T_M) \quad (B175)$$

$$L_{12} = \left[\left(\frac{12. (S_i)_{12}}{D_{L2} + D_{L1}} \right)^2 - \left(\frac{D_{L2} - D_{L1}}{2.} \right)^2 \right]^{1/2} \quad (B176)$$

If (E-50.) B177, B177, B179

$$\text{If } \left(\left| \frac{(S_i)_{12} - (S_i)_{12o}}{(S_i)_{12}} \right| - \epsilon_2 \right) \quad B179, B178, B178 \quad (B177)$$

$$(S_i)_{12o} = (S_i)_{12} \quad (B178)$$

go to B120

$$L_2 = L_1 + L_{12} \quad (B179)$$

$$\omega_2 = (w_L + w_{c2}) / w_{g2} \quad (B180)$$

$$\phi_2 = w_{v2} / w_{g2} \quad (B181)$$

$$\text{phase velocity ratio} = V_{g2} / V_{L2} \quad (B182)$$

$$\text{bulk temperature ratio} = T_{g2} / T_{L2} \quad (B183)$$

$$S_{i2} = S_{i1} + (S_i)_{12} \quad (B184)$$

$$Q_2 = Q_1 + Q_{12} \quad (B185)$$

We have now finished calculations for state 2. If we satisfy the following tests, the calculation is complete; if not, we reset several variables to establish state 1 as the beginning of the next mixing section interval and recalculate state 2.

$$\text{If } (T_{g2} - T_{L2}) \text{ B212, B212, B186}$$

$$\text{If } (w_{vo} - w_{c2}) \text{ B212, B212, B187}$$

(B186)

$$\text{If } (1.399 - c_3) \text{ B212, B212, B188}$$

(B187)

$$h_{fgc1} = h_{fgc2}$$

(B188)

$$C_{pv1} = C_{pv2}$$

(B189)

$$C_{pg1} = C_{pg2}$$

(B190)

$$U_1 = U_2$$

(B191)

$$(w_c/S_i)_1 = (w_c/S_i)_2$$

(B192)

$$w_{v1} = w_{v2}$$

(B193)

$$T_{L1} = T_{L2}$$

(B194)

$$T_{g1} = T_{g2}$$

(B195)

$$T_{g1}(R) = T_{g2}(R)$$

(B196)

$$V_{g1} = V_{g2}$$

(B197)

$$V_{L1} = V_{L2}$$

(B198)

$$V'_{L1} = V'_{L2}$$

(B199)

$$V'_{g1} = V'_{g2}$$

(B200)

$$T_{i1} = T_{i2}$$

(B201)

$$w_{c1} = w_{c2}$$

(B202)

$$w_{g1} = w_{g2}$$

(B203)

$$D_{L1} = D_{L2}$$

(B204)

$$D_{g1} = D_{g2}$$

(B205)

$$L_1 = L_2$$

(B206)

$$S_{i1} = S_{i2}$$

(B207)

$$Q_1 = Q_2 \quad (\text{B208})$$

$$(\text{Re})_{g1} = (\text{Re})_{g2} \quad (\text{B209})$$

$$(\text{Re})_{rg1} = (\text{Re})_{rg2} \quad (\text{B210})$$

$$\rho_{g1} = \rho_{g2} \quad (\text{B211})$$

go to B90

read input data for new case. (B212)

APPENDIX C
CONSTANT PRESSURE MIXING WITH NONCONDENSABLE
(ANALYTICAL MODELS IIa AND IIb)

Computational Procedure - Analytical Model IIa:

We begin by calculating the following quantities at the ejector inlet stagnation state (state o) and at the entrance to the mixing section (state 1).

$$\text{STATE} = 1. \quad (C1)$$

$$T_{Lo} = T_{go} / (T_{go} / T_{Lo}) \quad (C2)$$

$$T_{L1} = T_{Lo} \quad (C3)$$

$$p_{Lo} = p_{go} (p_{Lo} / p_{go}) \quad (C4)$$

$$p = p_{go} (p / p_{go}) \quad (C5)$$

$$\phi_o = w_{vo} / (w_{vo} + w_{nc}) \quad (C6)$$

$$w_{v1} = w_{vo} \quad (C7)$$

$$\phi_1 = \phi_o \quad (C8)$$

$$w_{go} = w_{nc} + w_{vo} \quad (C9)$$

$$w_{g1} = w_{go} \quad (C10)$$

$$A_{L1} = (\pi D_{L1}^2 / 4.) c_2 \quad (C11)$$

$$V_{L1} = C_{dL} (288. g_o (p_{Lo} - p) / \rho_L)^{1/2} \quad (C12)$$

$$w_L = 3600. V_{L1} \rho_L A_{L1} / 144. \quad (C13)$$

$$T_{go}(R)^* = T_{go} + 459.69 \quad (C14)$$

$$T_{go}(K) = 5. T_{go}(R) / 9. \quad (C15)$$

* All temperatures are in degrees F except as indicated by (R) or (K) which refer to the Rankine and Kelvin temperature scales, respectively.

Call SATT*(p, T_{go}, T_{sat})

$$\bar{K}_g = 1.3 \quad (C16)$$

Call GASP (T_{go}(K), w_{nc}, w_{vo}, W_{nc}, W_v, J, C_{pgo}, K_{go})

$$T_{gl}(R) = T_{go}(R) / (p_{go}/p) \frac{\bar{K}_g - 1.}{\bar{K}_g} \quad (C17)$$

$$T_{gl}(K) = 5. T_{gl}(R)/9. \quad (C18)$$

Call GASP (T_{gl}(K), w_{nc}, w_{vl}, W_{nc}, W_v, J, C_{pgl}, K_{gl})

$$\bar{K}_{go} = \bar{K}_g \quad (C19)$$

$$\bar{K}_g = (K_{go} + K_{gl})/2. \quad (C20)$$

If (| $\bar{K}_g - \bar{K}_{go}$ | - ϵ_4) C21, C17, C17

$$V_{gl} = C_{dg} \left[2. g_o J (C_{pgo} T_{go}(R) - C_{pgl} T_{gl}(R)) \right]^{1/2} \quad (C21)$$

$$T_{gl}(R) = \left[C_{pgo} T_{go}(R) - C_{dg}^2 (C_{pgo} T_{go}(R) - C_{pgl} T_{gl}(R)) \right] / C_{pgl} \quad (C22)$$

$$T_{gl} = T_{gl}(R) - 459.69 \quad (C23)$$

$$T_{gl}(K) = 5. T_{gl}(R)/9. \quad (C24)$$

$$X_{vl} = \frac{\frac{w_{vl}/W_v}{\frac{w_{vl}}{W_v} + \frac{w_{nc}}{W_{nc}}}}{\quad} \quad (C25)$$

Call CASP1 (T_{gl}(K), σ_{nc} , σ_v , α , t*, (ϵ/k)_v, (ϵ/k)_{nc}, W_{nc}, W_v,

P, X_{vl}, σ_{gl} , D_l, μ_{vl} , μ_{ncl} , μ_{gl})

Call CASP2 (p, X_{vl}, W_{nc}, W_v, J, T_{gl}(R), T_{gl}(K), μ_{ncl} , μ_{vl} ,

S_{nc}, S_v, σ_{gl} , ρ_{gl} , T_{gl}(K), C_{pgl}, C_{pnc}, C_{pvl})

$$R_{gl} = 1545.45 / ((1. - X_{vl}) W_{nc} + X_{vl} W_v) \quad (C26)$$

** Fortran Subroutines are identified in Appendix G.

$$C_{g1} = (g_o K_{g1} R_{g1} T_{g1} (R))^{1/2} \quad (C27)$$

$$M_1 = V_{g1} / C_{g1} \quad (C28)$$

$$A_{g1} = 144. w_{g1} / (3600. \rho_{g1} V_{g1}) \quad (C29)$$

$$D_{g1} = (4. (A_{g1} + A_{L1}) / \pi)^{1/2} \quad (C30)$$

$$\omega_1 = w_L / w_{g1} \quad (C31)$$

$$\omega_o = \omega_1 \quad (C32)$$

$$(w_c / S_i) = 0. \quad (C33)$$

$$w_{c1} = 0. \quad (C34)$$

$$L_1 = 0. \quad (C35)$$

$$S_{i1} = 0. \quad (C36)$$

$$Q_1 = 0. \quad (C37)$$

$$\text{phase velocity ratio} = V_{g1} / V_{L1} \quad (C38)$$

$$(Pr)_{g1} = C_{pg1} \mu_{g1} / K_{g1} \quad (C39)$$

$$\text{Call VISLIQ } (T_{L1}, \mu_{L1})$$

$$V_{r1} = |V_{g1} - V_{L1}| \quad (C40)$$

$$V'_{g1} = 0.75 V_{r1} \quad (C41)$$

$$V'_{L1} = 0.25 V_{r1} \quad (C42)$$

$$(Pr)_{L1} = C_{pL} \mu_{L1} / k_L \quad (C43)$$

$$D_{e1} = 4. A_{g1} / (\pi(D_{g1} + c_2 D_{L1})) \quad (C44)$$

$$(Re)_{g1} = 3600. \rho_{g1} V_{g1} D_{e1} / (12. \mu_{g1}) \quad (C45)$$

$$(Sc)_{g1} = \mu_{g1} / (\rho_{g1} D'_{g1}) \quad (C46)$$

$$T_{i1} = 0.85 T_{g1} \quad (C47)$$

$$E = 0. \quad (C48)$$

$$T_{i12} = 0. \quad (C49)$$

$$\Delta q_{12} = 0. \quad (C50)$$

$$T_{i1}(R) = T_{i1} + 459.69 \quad (C51)$$

$$T_{i1}(K) = 5. T_{i1}(R)/9. \quad (C52)$$

$$\text{Call SATP } (T_{i1}, P_{c1})$$

$$P_{vil} = P_{c1} \quad (C53)$$

$$\text{Call SATHFG } (T_{i1}, P_{c1}, h_{gcl}, h_{fcl})$$

$$h_{fgcl} = h_{gcl} - h_{fcl} \quad (C54)$$

$$\text{Call VISLIQ } (T_{i1}, \mu_{c1})$$

$$(Re)_{L1} = 3600. \rho_L V'_{L1} D_{L1} / (12. \mu_{L1}) \quad (C55)$$

$$\text{If } ((Re)_{L1} - 12,500.) \text{ C56, C56, C57}$$

$$h_{L1} = 1.86 (12. k_L / D_{L1}) (Re)_{L1}^{1/3} (Pr)_{L1}^{1/3} (\mu_{L1} / \mu_{c1})^{0.14} \quad (C56)$$

go to C58

$$h_{L1} = 0.023 (12. k_L / D_{L1}) (Re)_{L1}^{0.8} (Pr)_{L1}^{0.4} \quad (C57)$$

$$(Re)_{rg1} = 3600. \rho_{g1} V'_{g1} D_{e1} / (12. \mu_{g1}) \quad (C58)$$

$$\text{Call GASP3 } (T_{i1}(K), \sigma_{nc}, \sigma_v, \alpha, t^*, (\epsilon/k)_v, (\epsilon/k)_{nc}, W_{nc},$$

$$W_v, P, P_{vil}, \mu_{gil})$$

$$\text{If } ((Re)_{rg1} - 9000.) \text{ C59, C59, C60}$$

$$h_{G1} = 1.86 (12. k_{g1} / D_{e1}) (Re)_{rg1}^{1/3} (Pr)_{g1}^{1/3} (\mu_{g1} / \mu_{gil})^{0.14} \quad (C59)$$

go to C61

$$h_{G1} = 0.027 (12. k_{g1} / D_{e1}) (Re)_{rg1}^{0.8} (Pr)_{g1}^{1/3} (\mu_{g1} / \mu_{gil})^{0.14} \quad (C60)$$

$$(K_G \cdot P'_{nc})_1 = h_{G1} (\rho_{g1} D'_{e1} / k_{g1}) ((Sc)_{g1} / (Pr)_{g1})^{1/3} \quad (C61)$$

Call SATLQV (T_{i1}, v_{c1})

$$\rho_{c1} = 1./v_{c1} \quad (C62)$$

$$\tau_m = 3600. (w_c/S_i)_1 v'_{g1}/g' \quad (C63)$$

$$v'_{L1} = \left[\frac{\rho_{g1}}{\rho_L} \left(\frac{(Re)_{L1}}{(Re)_{rg1}} \right)^{0.2} v'_{g1}{}^2 + \frac{2. \tau_m (Re)_{L1}^{0.2} g'}{(0.046) 3600.{}^2 \rho_L} \right]^{1/2} \quad (C64)$$

$$v'_{g1} = |v_{r1} - v'_{L1}| \quad (C65)$$

$$P'_{nc1} = \frac{X_{v1} P - p_{vil}}{14.696 \ln \left(\frac{P - p_{vil}}{P - X_{v1} P} \right)} \quad (C66)$$

$$K_{G1} = (K_G \cdot P'_{nc})_1 / P'_{nc1} \quad (C67)$$

$$(w_c/S_i)_1 = K_{G1} (X_{v1} P - p_{vil}) / 14.696 \quad (C68)$$

$$(q_g/S_i)_1 = h_{G1} (T_{g1} - T_{i1}) + (w_c/S_i)_1 \left(h_{fgc1} + C_{pL} (T_{i1} - T_{L1}) + \frac{v_{g1}^2 - v_{L1}^2}{2. g_o J} \right) \quad (C69)$$

$$(q_L/S_i)_1 = h_{L1} (T_{i1} - T_{L1}) \quad (C70)$$

$$\Delta q_1 = (q_L/S_i)_1 - (q_g/S_i)_1 \quad (C71)$$

$$T_{i11} = T_{i12} \quad (C72)$$

$$\Delta q_{11} = \Delta q_{12} \quad (C73)$$

If (E-50.) C74, C74, C82

$$\text{If } \left(\frac{|T_{i1} - T_{i12}|}{T_{i1}} - \epsilon_1 \right) \text{ C82, C75, C75} \quad (C74)$$

$$T_{i12} = T_{i1} \quad (C75)$$

$$\Delta q_{12} = \Delta q_1 \quad (C76)$$

$$E = E + 1. \quad (C77)$$

If (E-3.) C78, C79, C79

$$T_{i1} = T_{i12} - \Delta q_{12} / (2 \cdot h_{L1}) \quad (C78)$$

go to C80

$$T_{i1} = (T_{i12} \Delta q_{11} - T_{i11} \Delta q_{12}) / (\Delta q_{11} - \Delta q_{12}) \quad (C79)$$

If $(T_{g1} - T_{i1})$ C81, C81, C51 (C80)

$$T_{i1} = T_{g1} - 0.1 \quad (C81)$$

go to C51

$$\Delta T_1 = T_{g1} - T_{L1} \quad (C82)$$

$$U = (q_L / S_i)_1 / \Delta T_1 \quad (C83)$$

$$\text{temperature ratio} = T_{g1} / T_{L1} \quad (C84)$$

At this point we have calculated all variables at state 1. We now commence our calculations for the first state 2.

$$\text{STATE} = \text{STATE} + 1. \quad (C85)$$

$$\Delta T_g = c_1 \Delta T_g \quad (C86)$$

If $(\Delta T_g - \epsilon_2)$ C88, C87, C87

$$\Delta T_g = \epsilon_2 \quad (C87)$$

$$T_{g2} = T_{g1} - \Delta T_g \quad (C88)$$

If $(T_{g2} - T_{sat})$ C90, C89, C89

$$T_{g2} = T_{sat} - 5. \quad (C89)$$

If $(T_{g2} - T_{L1} - \epsilon_6)$ C91, C92, C92 (C90)

$$T_{g2} = T_{L1} + \epsilon_6 \quad (C91)$$

Call SATP (T_{g2}, p_{v2}) (C92)

$$p_{g2} = p - p_{v2} \quad (C93)$$

$$X_{v2} = p_{v2}/p \quad (C94)$$

If $(X_{v1} - X_{v2})$ C91, C91, C92

$$T_{g2} = T_{g2} - 1. \quad (C95)$$

go to C92

$$w_{v2} = \left(\frac{X_{v2}}{1 - X_{v2}} \right) \frac{w_{nc} W_v}{W_{nc}} \quad (C96)$$

$$w_{g2} = w_{nc} + w_{v2} \quad (C97)$$

$$(w_c)_{12} = w_{g1} - w_{g2} \quad (C98)$$

$$w_{c2} = w_{v0} - w_{v2} \quad (C99)$$

If $\left(\frac{w_{c2}}{w_{v0}} - \epsilon_3 \right)$ C100, C234, C234

$$T_{g2}(R) = T_{g2} + 459.69 \quad (C100)$$

$$T_{g2}(K) = 5. T_{g2}(R)/9. \quad (C101)$$

Call GASP1 $(T_{g2}(K), \sigma_{nc}, \sigma_v, \alpha, t^*, (\epsilon/k)_v, (\epsilon/k)_{nc}, W_{nc}, W_v,$
 $p, X_{v2}, \sigma_{g2}, D'_{12}, \mu_{v2}, \mu_{nc2}, \mu_{g2})$

Call GASP2 $(p, X_{v2}, W_{nc}, W_v, J, T_{g2}(R), T_{g2}(K), \mu_{nc2}, \mu_{v2},$
 $S'_{nc}, S'_v, \sigma_{g2}, \rho_{g2}, T_{g2}(K), C_{pg2}, C_{pnc2}, C_{pv2})$

$$(Pr)_{g2} = C_{pg2} \mu_{g2}/k_{g2} \quad (C102)$$

$$\Delta h_v = C_{pv1} T_{g1}(R) - C_{pv2} T_{g2}(R) \quad (C103)$$

$$(q_v)_{12} = w_{v2} \Delta h_v \quad (C104)$$

$$\Delta h_{nc} = C_{pnc1} T_{g1}(R) - C_{pnc2} T_{g2}(R) \quad (C105)$$

$$(q_{nc})_{12} = w_{nc} \Delta h_{nc} \quad (C106)$$

$$(Sc)_{g2} = \mu_{g2}/(\rho_{g2} D'_{12}) \quad (C107)$$

$$V_{L2} = V_{L1} \quad (C108)$$

$$V_{g2} = V_{g1} \quad (C109)$$

$$T_{L2} = T_{L1} + \frac{(q_{nc})_{12} + (q_v)_{12} + (w_c)_{12} (h_{fgc1} + C_{pv2} (T_{g2} - T_{i1}))}{C_{pL} (w_L + w_{c1})} \quad (C110)$$

$$T_{i2} = (T_{g2} + T_{L2})/2. \quad (C111)$$

$$\bar{E} = 0. \quad (C112)$$

$$T_{i22} = 0. \quad (C113)$$

$$\Delta q_{22} = 0. \quad (C114)$$

$$V'_{g2} = V'_{g1} \quad (C115)$$

$$V'_{L2} = V'_{L1} \quad (C116)$$

$$(w_c/S_i)_{i2} = (w_c/S_i)_{i1} - 2. \quad (C117)$$

$$T_{i2}(R) = T_{i2} + 459.69 \quad (C118)$$

$$T_{i2}(K) = 5. T_{i2}(R)/9. \quad (C119)$$

$$\text{Call SATP}(T_{i2}, P_{vi2})$$

$$P_{c2} = P_{vi2} \quad (C120)$$

$$\text{Call SATHFG}(T_{i2}, P_{c2}, h_{gc2}, h_{fc2})$$

$$\text{Call SATLQV}(T_{i2}, v_{c2})$$

$$\text{Call SATSLIQ}(T_{i2}, \mu_{c2})$$

$$\rho_{c2} = 1./v_{c2} \quad (C121)$$

$$h_{fgc2} = h_{gc2} - h_{fc2} \quad (C122)$$

$$\Delta \bar{T}_{gc} = (T_{g1} + T_{g2} - T_{i1} - T_{i2})/2. \quad (C123)$$

$$\Delta \bar{h}_{vc} = (C_{pv1} + C_{pv2}) \Delta \bar{T}_{gc}/2. \quad (C124)$$

$$\bar{h}_{fgc} = (h_{fgc1} + h_{fgc2})/2. \quad (C125)$$

$$\Delta V_g = (V_{g1}^2 - V_{g2}^2) / (2 \cdot g_o J) \quad (C126)$$

$$\Delta V_L = (V_{L1}^2 - V_{L2}^2) / (2 \cdot g_o J) \quad (C127)$$

$$\Delta V_{gL} = (V_{g1}^2 - V_{L2}^2) / (2 \cdot g_o J) \quad (C128)$$

$$\Delta \bar{h}_{cL} = C_{pL} \left(\frac{T_{i1} + T_{i2}}{2} - T_{L2} \right) \quad (C129)$$

$$(q_v)_{12} = w_{v2} (\Delta h_v + \Delta V_g) \quad (C130)$$

$$(q_{nc})_{12} = w_{nc} (\Delta h_{nc} + \Delta V_g) \quad (C131)$$

$$(q_c)_{12} = (w_c)_{12} (\Delta \bar{h}_{vc} + \bar{h}_{fgc} + \Delta \bar{h}_{cL} + \Delta V_{gL}) \quad (C132)$$

$$(q_L)_{12} = (w_L + w_{c1}) \Delta V_L \quad (C133)$$

$$Q_{12} = (q_{nc})_{12} + (q_v)_{12} + (q_c)_{12} + (q_L)_{12} \quad (C134)$$

$$T_{L2} = T_{L1} + \frac{Q_{12}}{C_{pL} (w_L + w_{c1})} \quad (C135)$$

$$\Delta T_2 = T_{g2} - T_{L2} \quad (C136)$$

$$\Delta T_M = \frac{(T_{g1} - T_{L1}) - (T_{g2} - T_{L2})}{\ln \left(\frac{T_{g1} - T_{L1}}{T_{g2} - T_{L2}} \right)} \quad (C137)$$

Call VISLIQ (T_{L2} , μ_{L2})

$$(Pr)_{L2} = C_{pL} \mu_{L2} / k_L \quad (C138)$$

$$(w_c \bar{S}_i) = \frac{(w_c / S_i)_1 - (w_c / S_i)_2}{\ln \left(\frac{(w_c / S_i)_1}{(w_c / S_i)_2} \right)} \quad (C139)$$

$$(S_{ic})_{12} = (w_c)_{12} / (w_c \bar{S}_i) \quad (C140)$$

Sense Light 1

$$A_{g2} = 144 \cdot w_{g2} / (3600 \cdot \rho_{g2} V_{g2}) \quad (C141)$$

$$A_{L2} = 144. \left(\frac{w_L}{\rho_L V_{L2}} + \frac{w_{c2}}{\rho_{c2} V_{L2}} \right) / 3600. \quad (C142)$$

$$D_{L2} = (4. A_{L2} / (\pi c_2))^{1/2} \quad (C143)$$

$$D_{g2} = (4. (A_{g2} + A_{L2}) / \pi)^{1/2} \quad (C144)$$

$$\bar{D}_L = (D_{L1} + D_{L2}) / 2. \quad (C145)$$

$$\bar{D}_g = (D_{g1} + D_{g2}) / 2. \quad (C146)$$

$$D_{e2} = 4. A_{g2} / (\pi (D_{g2} + c_2 D_{L2})) \quad (C147)$$

$$V_{r2} = | V_{g2} - V_{L2} | \quad (C148)$$

$$L_{12} = \left[\left(\frac{12. (S_{ic})_{12}}{\pi c_2 \frac{D_{L2} + D_{L1}}{2.}} \right)^2 - \left(\frac{D_{L2} - D_{L1}}{2.} \right)^2 \right]^{1/2} \quad (C149)$$

$$\bar{V}_g = (V_{g1} + V_{g2}) / 2. \quad (C150)$$

$$\bar{V}'_g = (V'_{g1} + V'_{g2}) / 2. \quad (C151)$$

$$\bar{V}_L = (V_{L1} + V_{L2}) / 2. \quad (C152)$$

$$(Re)_{g2} = 3600. \rho_{g2} V_{g2} D_{e2} / (12. \mu_{g2}) \quad (C153)$$

$$(Re)_{rg2} = 3600. \rho_{g2} V'_{g2} D_{e2} / (12. \mu_{g2}) \quad (C154)$$

Call FORCE $(\bar{D}_L, \bar{D}_g, L_{12}, \bar{V}_g, \bar{V}'_g, (S_{ic})_{12}, (Re)_{g1}, (Re)_{g2},$
 $(Re)_{rg1}, (Re)_{rg2}, \rho_{g1}, \rho_{g2}, g', F_i, F_w)$

$$F_m = 3600. (w_c)_{12} \bar{V}'_g / g' \quad (C155)$$

$$F'_m = 3600. (w_c)_{12} (V'_{L1} + V'_{L2}) / (2. g') \quad (C156)$$

If $(\bar{V}_g - \bar{V}_L)$ C157, C160, C160

$$F_i = -F_i \quad (C157)$$

$$F_m = -F_m \quad (C158)$$

$$F'_m = -F'_m \quad (C159)$$

$$F = F_m + F_i \quad (C160)$$

$$\tau = F/(S_{ic})_{12} \quad (C161)$$

$$\tau_m = 3600. (w_c/S_i)_{12} V'_{g2}/g' \quad (C162)$$

$$(Re)_{L2} = 3600. \rho_L V'_{L2} D_{L2}/(12. \mu_{L2}) \quad (C163)$$

$$V_{L2} = \frac{3600. (w_L + w_{c1}) V_{L1} + g' (F + F'_m)}{3600. (w_L + w_{c2})} \quad (C164)$$

$$V_{g2} = \frac{3600. w_{g1} V_{g1} - g' (F + F'_w)}{3600. w_{g2}} \quad (C165)$$

$$V_{r2} = |V_{g2} - V_{L2}| \quad (C166)$$

$$V'_{L2} = \left[\frac{\rho_{g2}}{\rho_L} \left(\frac{(Re)_{L2}}{(Re)_{rg2}} \right)^{0.2} V'_{g2} + \frac{2. \tau_m (Re)_{L2}^{0.2} g'}{(0.046) 3600. \rho_L} \right]^{1/2} \quad (C167)$$

$$V'_{g2} = |V_{r2} - V'_{L2}| \quad (C168)$$

If (Sense Light 1) C141, C169

Call GASP3 ($T_{i2}(K)$, σ_{nc} , σ_v , α , t^* , $(\epsilon/k)_v$, $(\epsilon/k)_{nc}$, W_{nc} ,

$$W_v, P, P_{vi2}, \mu_{gi2}) \quad (C169)$$

If $((Re)_{rg2} - 9000.)$ C170, C170, C171

$$h_{G2} = 1.86 (12. k_{g2}/D_{e2}) (Re)_{rg2}^{1/3} (Pr)_{g2}^{1/3} (\mu_{g2}/\mu_{gi2})^{0.14} \quad (C170)$$

go to C172

$$h_{G2} = 0.027 (12. k_{g2}/D_{e2}) (Re)_{rg2}^{0.8} (Pr)_{g2}^{1/3} (\mu_{g2}/\mu_{gi2})^{0.14} \quad (C171)$$

$$(K_G \cdot P'_{nc})_2 = h_{G2} (\rho_{g2} D'_{12}/k_{g2}) ((Sc)_{g2}/(Pr)_{g2})^{1/3} \quad (C172)$$

If $((Re)_{L2} - 12,500.)$ C173, C173, C174

$$h_{L2} = 1.86 (12. k_L / D_{L2}) (Re)_{L2}^{1/3} (Pr)_{L2}^{1/3} (\mu_{L2} / \mu_{c2})^{0.14} \quad (C173)$$

go to C175

$$h_{L2} = 0.023 (12. k_L / D_{L2}) (Re)_{L2}^{0.8} (Pr)_{L2}^{0.4} \quad (C174)$$

$$P'_{nc2} = \frac{\sum v_2 P - P_{vi2}}{14.696 \ln \left(\frac{P - P_{vi2}}{P - \sum v_2 P} \right)} \quad (C175)$$

$$K_{G2} = (K_G \cdot P'_{nc2}) / P'_{nc2} \quad (C176)$$

$$(w_c / S_i)_2 = K_{G2} (\sum v_2 P - P_{vi2}) / 14.696 \quad (C177)$$

$$(q_g / S_i)_2 = h_{G2} (T_{g2} - T_{i2}) + (w_c / S_i)_2 \left(h_{fgc2} + C_{pL} (T_{i2} - T_{L2}) + \frac{v_{g2}^2 - v_{L2}^2}{2 \cdot g_o J} \right) \quad (C178)$$

$$(q_L / S_i)_2 = h_{L2} (T_{i2} - T_{L2}) \quad (C179)$$

$$\Delta q_2 = (q_L / S_i)_2 - (q_g / S_i)_2 \quad (C180)$$

$$T_{i21} = T_{i22} \quad (C181)$$

$$\Delta q_{21} = \Delta q_{22} \quad (C182)$$

If (E-50.) C183, C183, C191

$$\text{If } \left(\left| (T_{i2} - T_{i22}) / T_{i2} \right| - \epsilon_1 \right) 191, \text{ C184, C184} \quad (C183)$$

$$T_{i22} = T_{i2} \quad (C184)$$

$$\Delta q_{22} = \Delta q_2 \quad (C185)$$

$$E = E + 1. \quad (C186)$$

If (E-2.) C187, C188, C188

$$T_{i2} = T_{i22} - \Delta q_{22} / (2 \cdot h_{L2}) \quad (C187)$$

go to C189

$$T_{i2} = (T_{i22} \Delta q_{21} - T_{i21} \Delta q_{22}) / (\Delta q_{21} - \Delta q_{22}) \quad (C188)$$

$$\text{If } (T_{g2} - T_{i2}) \text{ C190, C190, C118} \quad (\text{C189})$$

$$T_{i2} = T_{g2}^{-0.1} \quad (\text{C190})$$

go to C118

$$U_2 = (q_L / S_{i2}) / \Delta T_2 \quad (\text{C191})$$

$$(w_c \bar{S}_i) = \frac{(w_c / S_{i1}) - (w_c / S_{i2})}{\ln \left(\frac{(w_c / S_{i1})}{(w_c / S_{i2})} \right)} \quad (\text{C192})$$

$$(S_i)_{12} = (w_c)_{12} / (w_c \bar{S}_i) \quad (\text{C193})$$

$$\bar{U} = Q_{12} / ((S_i)_{12} \Delta T_m) \quad (\text{C194})$$

$$L_{12} = \left[\left(\frac{12. (S_i)_{12}}{\pi c_2 \frac{D_{L2} + D_{L1}}{2}} \right)^2 - \left(\frac{D_{L2} - D_{L1}}{2} \right)^2 \right]^{1/2} \quad (\text{C195})$$

$$L_2 = L_1 + L_{12} \quad (\text{C196})$$

$$\omega_2 = (w_L + w_{c2}) / w_{g2} \quad (\text{C197})$$

$$\phi_2 = w_{v2} / w_{g2} \quad (\text{C198})$$

$$\text{temperature ratio} = T_{g2} / T_{L2} \quad (\text{C199})$$

$$\text{phase velocity ratio} = V_{g2} / V_{L2} \quad (\text{C200})$$

$$S_{i2} = S_{i1} + (S_i)_{12} \quad (\text{C201})$$

$$Q_2 = Q_1 + Q_{12} \quad (\text{C202})$$

$$\text{percent of vapor condensed} = 100. w_{c2} / w_{vo} \quad (\text{C203})$$

$$R_{g2} = 1545.45 / ((1. - X_{v2}) W_{nc} + X_{v2} W_v) \quad (\text{C204})$$

$$\text{Call GASP } (T_{g2}(\text{K}), w_{nc}, w_{v2}, W_{nc}, W_v, J, C_{pg2}, K_{g2})$$

$$C_{g2} = (g_o K_{g2} R_{g2} T_{g2}(\text{R}))^{1/2} \quad (\text{C205})$$

$$M_2 = V_{g2} / C_{g2} \quad (\text{C206})$$

We have now finished calculations for state 2. If we satisfy the following tests, the calculation is complete; if not, we reset several variables to establish state 1 as the beginning of the next mixing section interval and recalculate state 2.

$$\text{If } (T_{g2} - T_{L2}) \text{ C234, C234, C207}$$

$$\text{If } (w_{vo} - w_{c2}) \text{ C234, C234, C208} \quad (\text{C207})$$

$$\text{If } (T_{g2} - T_{L2} - \epsilon_6) \text{ C234, C234, C209} \quad (\text{C208})$$

$$h_{fgc1} = h_{fgc2} \quad (\text{C209})$$

$$C_{pv1} = C_{pv2} \quad (\text{C210})$$

$$C_{pnc1} = C_{pnc2} \quad (\text{C211})$$

$$C_{pg1} = C_{pg2} \quad (\text{C212})$$

$$U_1 = U_2 \quad (\text{C213})$$

$$(w_c/S_i)_1 = (w_c/S_i)_2 \quad (\text{C214})$$

$$w_{v1} = w_{v2} \quad (\text{C215})$$

$$T_{L1} = T_{L2} \quad (\text{C216})$$

$$T_{g1} = T_{g2} \quad (\text{C217})$$

$$T_{g1}(R) = T_{g2}(R) \quad (\text{C218})$$

$$T_{i1} = T_{i2} \quad (\text{C219})$$

$$V_{g1} = V_{g2} \quad (\text{C220})$$

$$V_{L1} = V_{L2} \quad (\text{C221})$$

$$V'_{L1} = V'_{L2} \quad (\text{C222})$$

$$V'_{g1} = V'_{g2} \quad (\text{C223})$$

$$w_{c1} = w_{c2} \quad (\text{C224})$$

$$w_{g1} = w_{g2} \quad (\text{C225})$$

$$D_{L1} = D_{L2} \quad (C226)$$

$$D_{g1} = D_{g2} \quad (C227)$$

$$L_1 = L_2 \quad (C228)$$

$$S_{i1} = S_{i2} \quad (C229)$$

$$Q_1 = Q_2 \quad (C230)$$

$$(Re)_{g1} = (Re)_{g2} \quad (C231)$$

$$(Re)_{rg1} = (Re)_{rg2} \quad (C232)$$

$$\rho_{g1} = \rho_{g2} \quad (C233)$$

go to C85

read in data for new case (C234)

Computational Procedure - Analytical Model IIb:

The computational procedure for Analytical Model IIb is essentially the same as that for Analytical Model IIa. The differences which are listed below are the result of simplifying the relative velocity between phases such that

$$V_r = V_g - V_L = V'_g + V'_L \quad (C235)$$

Thus, all equations in the computational procedure for Analytical Model IIa which contain the relative velocities, V'_g or V'_L , are revised to use the single relative velocity, V_r .

Delete equations C41 and C42.

Equation C55 becomes

$$(Re)_{L1} = 3600. \rho_L V_{r1} D_{L1} / (12. \mu_{L1}) \quad (C55)$$

Equation C58 becomes

$$(Re)_{rg1} = 3600. \rho_{g1} V_{r1} D_{e1} / (12. \mu_{g1}) \quad (C58)$$

Equation C63 becomes

$$\tau_m = 3600. (w_c / S_i) V_{r1} / g' \quad (C63)$$

Delete equations C64 and C65.

Delete equations C115, C116 and C151.

Equation C154 becomes

$$(Re)_{rg2} = 3600. \rho_{g2} V_{r2} D_{e2} / (12. \mu_{g2}) \quad (C154)$$

Call FORCE with \bar{V}_L in lieu of \bar{V}'_g .*

Equation C155 becomes

$$F_m = 3600. (w_c)_{12} (\bar{V}_g - \bar{V}_L) / g' \quad (C155)$$

Delete equations C156, C159, and C162.

Equation C163 becomes

$$(Re)_{L2} = 3600. \rho_L V_{r2} D_{L2} / (12. \mu_{L2}) \quad (C163)$$

Equation C164 becomes

$$V_{L2} = \frac{3600. (w_L + w_{c1}) V_{L1} + (g' F)}{3600. (w_L + w_{c2})} \quad (C164)$$

Delete equations C167 and C168.

Delete equations C222 and C223.

* Subroutine Force is revised slightly to account for this change.
(See Appendix G.)

APPENDIX D
CONSTANT AREA MIXING WITH NONCONDENSABLE
(ANALYTICAL MODEL III)

Computational Procedure:

We begin by calculating the following quantities at the ejector inlet state (state o) and at the entrance to the mixing section (state l).

$$\text{STATE} = 1. \quad (\text{D1})$$

$$T_{Lo} = T_{go} / (T_{go} / T_{Lo}) \quad (\text{D2})$$

$$T_{Ll} = T_{Lo} \quad (\text{D3})$$

$$P_{Lo} = P_{go} (P_{Lo} / P_{go}) \quad (\text{D4})$$

$$\phi_o = w_{vo} / (w_{vo} + w_{nc}) \quad (\text{D5})$$

$$\phi_l = \phi_o \quad (\text{D6})$$

$$w_{vl} = w_{vo} \quad (\text{D7})$$

$$w_{go} = w_{nc} + w_{vo} \quad (\text{D8})$$

$$w_{gl} = w_{go} \quad (\text{D9})$$

$$A_{Ll} = c_2 (\pi D_{Ll}^2 / 4.) \quad (\text{D10})$$

$$T_{go}(R)^* = T_{go} + 459.69 \quad (\text{D11})$$

$$T_{go}(K) = 5. T_{go}(R) / 9. \quad (\text{D12})$$

$$X_{vl} = \frac{\frac{w_{vl}}{W_v}}{\frac{w_{vl}}{W_v} + \frac{w_{nc}}{W_{nc}}} \quad (\text{D13})$$

Call GASP** ($T_{go}(K)$, w_{nc} , w_{vo} , W_{nc} , W_v , R , C_{pgo} , K_{go})

* All temperatures are in degrees F except as indicated by (R) or (K) which refer to the Rankine and Kelvin temperature scales, respectively.

** Fortran Subroutines are identified in Appendix G.

$$C_{pgl} = C_{pgo} \quad (D14)$$

$$K_{gl} = K_{go} \quad (D15)$$

$$R_{gl} = 1545.45 / ((1. - X_{vl}) W_{nc} + X_{vl} W_v) \quad (D16)$$

$$T_{gl} = \left(\frac{2. C_{dg}^2 J C_{pgo} T_{go}(R)}{M_1^2 K_{gl} R_{gl} + 2. C_{dg}^2 J C_{pgl}} \right) - 459.69 \quad (D17)$$

$$T_{gl}(R) = T_{gl} + 459.69 \quad (D18)$$

$$T_{gl}(K) = 5. T_{gl}(R)/9. \quad (D19)$$

$$\text{Call GASP } (T_{gl}(K), w_{nc}, w_{vl}, W_{nc}, W_v, R', C_{pgl}, K_{gl})$$

$$V_{gl} = C_{dg} \left[2. g_o J (C_{pgo} T_{go}(R) - C_{pgl} T_{gl}(R)) \right]^{1/2} \quad (D20)$$

$$C_{gl} = V_{gl}/M_1 \quad (D21)$$

$$\bar{K}_g = (K_{go} + K_{gl})/2. \quad (D22)$$

$$P_1 = P_{go} / (T_{go}(R)/T_{gl}(R)) \frac{\bar{K}_g}{\bar{K}_g - 1}. \quad (D23)$$

$$V_{L1} = C_{dL} (288. g_o (P_{Lo} - P_1)/\rho_L)^{1/2} \quad (D24)$$

$$w_L = 3600. \rho_L V_{L1} A_{L1}/144. \quad (D25)$$

$$\text{Call SATT } (P_1, T_{gl}, T_{sat 1})$$

$$\text{Call CASP1 } (T_{gl}(K), \sigma_{nc}, \sigma_v, \alpha, t^*, (\epsilon/k)_v, (\epsilon/k)_{nc}, W_{nc}, W_v,$$

$$P_1, X_{vl}, \sigma_{gl}, D'_1, \mu_{vl}, \mu_{ncl}, \mu_{gl})$$

$$\text{Call CASP2 } (P_1, X_{vl}, W_{nc}, W_v, R', T_{gl}(R), T_{gl}(K), \mu_{ncl},$$

$$\mu_{vl}, S'_{nc}, S'_v, \sigma_{gl}, \rho_{gl}, k_{gl}, C_{pgl}, C_{pncl}, C_{pvl})$$

$$A_{gl} = 144. w_{gl}/(3600. \rho_{gl} V_{gl}) \quad (D26)$$

$$D_{g1} = (4. (A_{g1} + A_{L1})/\pi)^{1/2} \quad (D27)$$

$$\omega_1 = w_L/w_{g1} \quad (D28)$$

$$\omega_o = \omega_1 \quad (D29)$$

$$w_{c1} = 0. \quad (D30)$$

$$L_1 = 0. \quad (D31)$$

$$S_{i1} = 0. \quad (D32)$$

$$Q_1 = 0. \quad (D33)$$

$$\text{phase velocity ratio} = V_{g1}/V_{L1} \quad (D34)$$

$$\text{bulk temperature ratio} = T_{g1}/T_{L1} \quad (D35)$$

$$(Pr)_{g1} = C_{pg1} \mu_{g1}/k_{g1} \quad (D36)$$

$$\text{Call VISLIQ } (T_{L1}, \mu_{L1})$$

$$V_{r1} = |V_{g1} - V_{L1}| \quad (D37)$$

$$(Pr)_{L1} = C_{pL} \mu_{L1}/k_L \quad (D38)$$

$$D_{e1} = 4. A_{g1}/(\pi(D_{g1} + c_2 D_{L1})) \quad (D39)$$

$$(Re)_{g1} = 3600. \rho_{g1} V_{g1} D_{e1}/(12. \mu_{g1}) \quad (D40)$$

$$(Sc)_{g1} = \mu_{g1}/(\rho_{g1} D_{e1}) \quad (D41)$$

$$(w_c/S_i)_1 = 0. \quad (D42)$$

$$T_{i1} = 0.85 T_{g1} \quad (D43)$$

$$V'_{g1} = 0.75 V_{r1} \quad (D44)$$

$$V'_{L1} = 0.25 V_{r1} \quad (D45)$$

$$T_{i12} = 0. \quad (D46)$$

$$\Delta q_{12} = 0. \quad (D47)$$

$$E = 0. \quad (D48)$$

$$T_{il}(R) = T_{il} + 459.69 \quad (D49)$$

$$T_{il}(K) = 5. T_{il}(R)/9. \quad (D50)$$

$$\text{Call SATP } (T_{il}, P_{vil})$$

$$\text{Call SATHFG } (T_{il}, P_{vil}, h_{gcl}, h_{fcl})$$

$$\text{Call VISLIQ } (T_{il}, \mu_{cl})$$

$$h_{fgcl} = h_{gcl} - h_{fcl} \quad (D51)$$

$$(Re)_{L1} = 3600. \rho_L V'_{L1} D_{L1} / (12. \mu_{L1}) \quad (D52)$$

$$\text{If } ((Re)_{L1} - 12,500.) \text{ D53, D53, D54}$$

$$h_{L1} = 1.86 (12. k_L / D_{L1}) (Re)_{L1}^{1/3} (Pr)_{L1}^{1/3} (\mu_{L1} / \mu_{cl})^{0.14} \quad (D53)$$

go to D55

$$h_{L1} = 0.023 (12. k_L / D_{L1}) (Re)_{L1}^{0.8} (Pr)_{L1}^{0.4} \quad (D54)$$

$$(Re)_{rg1} = 3600. \rho_{g1} V'_{g1} D_{el} / (12. \mu_{g1}) \quad (D55)$$

$$\text{Call GASP3 } (T_{il}(K), \sigma_{nc}, \sigma_v, \alpha, \epsilon^*, (\epsilon/k)_v, (\epsilon/k)_{nc}, W_{nc}, W_v,$$

$$P_1, P_{vil}, \mu_{gil})$$

$$\text{If } ((Re)_{rg1} - 9000.) \text{ D56, D56, D57}$$

$$h_{G1} = 1.86 (12. k_{g1} / D_{el}) (Re)_{rg1}^{1/3} (Pr)_{g1}^{1/3} (\mu_{g1} / \mu_{gil})^{0.14} \quad (D56)$$

go to D58

$$h_{G1} = 0.027 (12. k_{g1} / D_{el}) (Re)_{rg1}^{0.8} (Pr)_{g1}^{1/3} (\mu_{g1} / \mu_{gil})^{0.14} \quad (D57)$$

$$(K_G \cdot P'_{nc})_1 = h_{G1} (\rho_{g1} D'_{11} / k_{g1}) ((Sc)_{g1} / (Pr)_{g1})^{1/3} \quad (D58)$$

$$\tau_m = 3600. (w_c / S_{i1}) V'_{g1} / g' \quad (D59)$$

$$V'_{L1} = \left[\frac{\rho_{g1}}{\rho_L} \left(\frac{(Re)_{L1}}{(Re)_{rg1}} \right)^{0.2} V'_{g1}^2 + \frac{2. \tau_m (Re)_{L1}^{0.2} g'}{(0.046) 3600.^2 \rho_L} \right]^{1/2} \quad (D60)$$

$$V'_{g1} = |V_{r1} - V'_{L1}| \quad (D61)$$

$$P'_{nc1} = \frac{X_{v1} P_1 - P_{v1}}{14.696 \ln \left(\frac{P_1 - P_{v1}}{P_1 - X_{v1} P_1} \right)} \quad (D62)$$

$$K_{G1} = (K_G \cdot P'_{nc1}) / P'_{nc1} \quad (D63)$$

$$(w_c / S_i)_1 = K_{G1} (X_{v1} P_1 - P_{v1}) / 14.696 \quad (D64)$$

$$(q_g / S_i)_1 = h_{G1} (T_{g1} - T_{i1}) + (w_c / S_i)_1 \left(h_{fgc1} + C_{pL} (T_{i1} - T_{L1}) + \frac{V_{g1}^2 - V_{L1}^2}{2 \cdot g_o J} \right) \quad (D65)$$

$$(q_L / S_i)_1 = h_{L1} (T_{i1} - T_{L1}) \quad (D66)$$

$$\Delta q_1 = (q_L / S_i)_1 - (q_g / S_i)_1 \quad (D67)$$

$$T_{i11} = T_{i12} \quad (D68)$$

$$\Delta q_{11} = \Delta q_{12} \quad (D69)$$

If (E-50.) D70, D70, D78

$$\text{If } \left| (T_{i1} - T_{i12}) / T_{i1} \right| - \epsilon_1 \text{ D78, D78, D71} \quad (D70)$$

$$T_{i12} = T_{i1} \quad (D71)$$

$$\Delta q_{12} = \Delta q_1 \quad (D72)$$

$$E = E + 1. \quad (D73)$$

If (E-3.) D74, D75, D75

$$T_{i1} = T_{i12} - \Delta q_{12} / (2 \cdot h_{L1}) \quad (D74)$$

go to D76

$$T_{i1} = (T_{i12} \Delta q_{11} - T_{i11} \Delta q_{12}) / \Delta q_{11} - \Delta q_{12} \quad (D75)$$

$$\text{If } (T_{g1} - T_{i1}) \quad (D76)$$

$$T_{i1} = T_{g1} - 0.1 \quad (D77)$$

go to D49

$$\Delta T_1 = T_{g1} - T_{L1} \quad (D78)$$

$$U_1 = (q_L / S_{i1}) / \Delta T_1 \quad (D79)$$

At this point we have calculated all variables at state 1. We now commence our calculations for the first state 2.

$$D_{g2} = D_{g1} \quad (D80)$$

$$\bar{D}_g = D_{g1} \quad (D81)$$

$$STATE = STATE + 1. \quad (D82)$$

$$\Delta T_g = c_1 \Delta T_g \quad (D83)$$

If $(\Delta T_g - \epsilon_2)$ D85, D84, D84

$$\Delta T_g = \epsilon_2 \quad (D84)$$

$$T_{g2} = T_{g1} - \Delta T_g \quad (D85)$$

If $(T_{g2} - T_{L1} - \epsilon_6)$ D86, D87, D87

$$T_{g2} = T_{L1} + \epsilon_6 \quad (D86)$$

$$T_{g2}(R) = T_{g2} + 459.69 \quad (D87)$$

$$T_{g2}(K) = 5. T_{g2} / 9. \quad (D88)$$

Call SATP (T_{g2}, P_{v2})

$$P_2 = P_1 \quad (D89)$$

$$X_{v2} = P_{v2} / P_2 \quad (D90)$$

If $(X_{v1} - X_{v2})$ D91, D91, D92

$$T_{g2} = T_{g2} - 1. \quad (D91)$$

go to D87

$$V_{L2} = V_{L1} \quad (D92)$$

$$V_{g2} = V_{g1} \quad (D93)$$

$$V'_{L2} = V'_{L1} \quad (D94)$$

$$V'_{g2} = V'_{g1} \quad (D95)$$

$$(w_c/S_i)_2 = (w_c/S_i)_1 - 2. \quad (D96)$$

$$w_{v2} = \frac{X_{v2}}{1 - X_{v2}} \left(\frac{w_{nc} W_v}{W_{nc}} \right) \quad (D97)$$

$$w_{g2} = w_{nc} + w_{v2} \quad (D98)$$

$$(w_c)_{12} = w_{g1} - w_{g2} \quad (D99)$$

$$T_{L2} = T_{L1} + \frac{C_{pg1} (T_{g1} - T_{g2}) + (w_c)_{12} (h_{fgc1} + C_{pvl} (T_{g2} - T_{i1}))}{C_{pL} (w_L + w_{c1})} \quad (D100)$$

$$T_{i1} = (T_{g2} + T_{L2}) / 2. \quad (D101)$$

$$T_{i22} = 0. \quad (D102)$$

$$\Delta q_{22} = 0. \quad (D103)$$

$$E = 0. \quad (D104)$$

$$T_{i2}(R) = T_{i2} + 459.69 \quad (D105)$$

$$T_{i2}(K) = 5. T_{i2}(R)/9. \quad (D106)$$

Sense Light 1

$$P_{nc2} = P_2 - P_{v2} \quad (D107)$$

$$X_{v2} = P_{v2}/P_2 \quad (D108)$$

If $(X_{v1} - X_{v2})$ D233, D233, D109

$$w_{v2} = \frac{X_{v2}}{1 - X_{v2}} \left(\frac{w_{nc} W_v}{W_{nc}} \right) \quad (D109)$$

$$w_{g2} = w_{nc} + w_{v2} \quad (D110)$$

$$(w_c)_{12} = w_{g1} - w_{g2} \quad (D111)$$

$$w_{c2} = w_{v0} - w_{v2} \quad (D112)$$

$$\text{If } \left(\frac{w_{c2}}{w_{v0}} - \epsilon_3 \right) \text{ D113, D233, D233}$$

$$R_{g2} = 1545.45 / ((1 - X_{v2}) W_{nc} + X_{v2} W_v) \quad (D113)$$

$$\text{Call GASP } (T_{g2}(K), w_{nc}, w_{v2}, W_{nc}, W_v, R', C_{pg2}, K_{g2})$$

$$C_{g2} = (g_o K_{g2} R_{g2} T_{g2}(R))^{1/2} \quad (D114)$$

$$\text{Call GASP1 } (T_{g2}(K), \sigma_{nc}, \sigma_v, \alpha, t^*, (\epsilon/k)_v, (\epsilon/k)_{nc}, W_{nc}, W_v,$$

$$p_2, X_{v2}, \sigma_{g2}, D'_2, \mu_{v2}, \mu_{nc2}, \mu_{g2})$$

$$\text{Call GASP2 } (p_2, X_{v2}, W_{nc}, W_v, R', T_{g2}(R), T_{g2}(K), \mu_{nc2}, \mu_{v2},$$

$$S'_{nc}, S'_v, \sigma_{g2}, \rho_{g2}, k_{g2}, C_{pg2}, C_{pnc2}, C_{pv2})$$

$$(Pr)_{g2} = C_{pg2} \mu_{g2} / k_{g2} \quad (D115)$$

$$\Delta h_v = C_{pv1} T_{g1}(R) - C_{pv2} T_{g2}(R) \quad (D116)$$

$$(q_v)_{12} = w_{v2} \Delta h_v \quad (D117)$$

$$\Delta h_{nc} = C_{pnc1} T_{g1}(R) - C_{pnc2} T_{g2}(R) \quad (D118)$$

$$(q_{nc})_{12} = w_{nc} \Delta h_{nc} \quad (D119)$$

$$(Sc)_{g2} = \mu_{g2} / (\rho_{g2} D'_2) \quad (D120)$$

$$\text{Call SATT } (p_2, T_{g2}, T_{sat2})$$

$$\text{Call SATP } (T_{i2}, p_{vi2})$$

$$\text{Call SATHFG } (T_{i2}, p_{vi2}, h_{gc2}, h_{fc2})$$

$$\text{Call SATLQV } (T_{i2}, v_{c2})$$

$$\text{Call VISLIQ } (T_{i2}, \mu_{c2})$$

$$\rho_{c2} = 1. / v_{c2} \quad (D121)$$

$$h_{fgc2} = h_{gc2} - h_{fc2} \quad (D122)$$

$$\Delta \bar{T}_{gc} = (T_{g1} + T_{g2} - T_{i1} - T_{i2})/2. \quad (D123)$$

$$\Delta \bar{h}_{vc} = (C_{pv1} + C_{pv2}) \Delta \bar{T}_{gc}/2. \quad (D124)$$

$$\bar{h}_{fgc} = (h_{fgc1} + h_{fgc2})/2. \quad (D125)$$

$$\Delta_p = 144. (p_1 - p_2)/(\rho_L J) \quad (D126)$$

$$\Delta V_g = (V_{g1}^2 - V_{g2}^2)/(2 \cdot g_o J) \quad (D127)$$

$$\Delta V_L = (V_{L1}^2 - V_{L2}^2)/(2 \cdot g_o J) \quad (D128)$$

$$\Delta V_{gL} = (V_{g1}^2 - V_{L2}^2)/(2 \cdot g_o J) \quad (D129)$$

$$\Delta \bar{h}_{cL} = C_{pL} \left(\frac{T_{i1} + T_{i2}}{2} - T_{L2} \right) \quad (D130)$$

$$(q_v)_{12} = w_{v2} (\Delta h_v + \Delta V_g) \quad (D131)$$

$$(q_{nc})_{12} = w_{nc} (\Delta h_{nc} + \Delta V_g) \quad (D132)$$

$$(q_c)_{12} = (w_c)_{12} (\bar{h}_{fgc} + \Delta \bar{h}_{vc} + \Delta \bar{h}_{cL} + \Delta \bar{V}_{gL}) \quad (D133)$$

$$(q_L)_{12} = (w_L + w_{c1}) \Delta V_L \quad (D134)$$

$$Q_{12} = (q_{nc})_{12} + (q_v)_{12} + (q_c)_{12} + (q_L)_{12} \quad (D135)$$

$$T_{L2} = T_{L1} + \frac{Q_{12}}{C_{pL} (w_L + w_{c1})} \quad (D136)$$

$$\Delta T_2 = T_{g2} - T_{L2} \quad (D137)$$

$$\Delta T_M = \frac{(T_{g1} - T_{L1}) - (T_{g2} - T_{L2})}{\ln \left(\frac{T_{g1} - T_{L1}}{T_{g2} - T_{L2}} \right)} \quad (D138)$$

$$\text{Call VISLIQ } (T_{L2}, \mu_{L2})$$

$$(Pr)_{L2} = C_{pL} \mu_{L2} / k_L \quad (D139)$$

$$(\overline{w_c/S_i}) = \frac{(w_c/S_i)_1 - (w_c/S_i)_2}{\ln \left(\frac{(w_c/S_i)_1}{(w_c/S_i)_2} \right)} \quad (D140)$$

$$(S_{ic})_{12} = (w_c)_{12} / (\overline{w_c/S_i}) \quad (D141)$$

$$A_{L2} = 144. \left(\frac{w_L}{\rho_L V_{L2}} + \frac{w_{c2}}{\rho_{c2} V_{L2}} \right) / 3600. \quad (D142)$$

$$D_{L2} = (4. A_{L2} / (\pi c_2))^{1/2} \quad (D143)$$

$$A_{g2} = (\pi D_{g2}^2 / 4.) - A_{L2} \quad (D144)$$

$$\overline{D}_L = (D_{L1} + D_{L2}) / 2. \quad (D145)$$

$$V_{g2} = 144. w_{g2} / (3600. \rho_{g2} A_{g2}) \quad (D146)$$

$$D_{e2} = 4. A_{g2} / (\pi (D_{g2} + c_2 D_{L2})) \quad (D147)$$

$$V_{r2} = |V_{g2} - V_{L2}| \quad (D148)$$

$$L_{12} = \left[\left(\frac{12. (S_{ic})_{12}}{\pi c_2 \frac{D_{L2} + D_{L1}}{2.}} \right)^2 - \left(\frac{D_{L2} - D_{L1}}{2.} \right)^2 \right]^{1/2} \quad (D149)$$

$$\overline{V}_g = (V_{g1} + V_{g2}) / 2. \quad (D150)$$

$$\overline{V}'_g = (V'_{g1} + V'_{g2}) / 2. \quad (D151)$$

$$\overline{V}_L = (V_{L1} + V_{L2}) / 2. \quad (D152)$$

$$(Re)_{g2} = 3600. \rho_{g2} V_{g2} D_{e2} / (12. \mu_{g2}) \quad (D153)$$

$$(Re)_{rg2} = 3600. \rho_{g2} V'_{g2} D_{e2} / (12. \mu_{g2}) \quad (D154)$$

$$\text{Call FORCE } (\overline{D}_L, \overline{D}_g, L_{12}, \overline{V}_g, \overline{V}'_g, (S_{ic})_{12}, (Re)_{g1}, (Re)_{g2},$$

$$(Re)_{rg1}, (Re)_{rg2}, \rho_{g1}, \rho_{g2}, g', F_i, F_w)$$

$$F_m = 3600. (w_c)_{12} \overline{V}'_g / g' \quad (D155)$$

$$F'_m = 3600. (w_c)_{12} (V'_{L1} + V'_{L2}) / (2. g') \quad (D156)$$

If $(\bar{V}_g - \bar{V}_L)$ D157, D160, D160

$$F_i = -F_i \quad (D157)$$

$$F_m = -F_m \quad (D158)$$

$$F'_m = -F'_m \quad (D159)$$

$$F = F_m + F_i \quad (D160)$$

$$\tau = |F / (S_{ic})_{12}| \quad (D161)$$

$$\tau_m = 3600. (w_c / S_i)_{12} V'_{g2} / g' \quad (D162)$$

$$(Re)_{L2} = 3600. \rho_L V'_{L2} D_{L2} / (12. \mu_{L2}) \quad (D163)$$

$$V_{L2} = \frac{(p_1 A_{L1} - p_2 A_{L2}) g' + 3600. (w_L + w_{c1}) V_{L1} + g' (F + F'_m) - \frac{p_1 + p_2}{2.} (A_{L1} - A_{L2}) g'}{3600. (w_L + w_{c2})} \quad (D164)$$

$$V_{r2} = |V_{g2} - V_{L2}| \quad (D165)$$

$$V'_{L2} = \left[\frac{\rho_{g2}}{\rho_L} \left(\frac{(Re)_{L2}}{(Re)_{rg2}} \right)^{0.2} V'_{g2}^2 + \frac{2. \tau_m (Re)_{L2}^{0.2} g'}{(0.046) 3600. \rho_L} \right]^{1/2} \quad (D166)$$

$$V'_{g2} = |V_{r2} - V'_{L2}| \quad (D167)$$

$$p_2 = p_1 + \frac{3600. (w_{g1} V_{g1} - w_{g2} V_{g2}) - g' (F + F_w)}{g' (A_{g1} + A_{g2}) / 2.} \quad (D168)$$

If (Sense Light 1) D107, D169

Call GASP3 $(T_{i2}(K), \sigma_{nc}, \sigma_v, \alpha, t^*, (\epsilon/k)_v, (\epsilon/k)_{nc}, W_{nc}, W_v,$

$$p_2, p_{vi2}, \mu_{gi2}) \quad (D169)$$

If $((Re)_{rg2} - 9000.)$ D170, D170, D171

$$h_{G2} = 1.86 (12.k_{g2}/D_{e2}) (Re)_{rg2}^{1/3} (Pr)_{g2}^{1/3} (\mu_{g2}/\mu_{gi2})^{0.14} \quad (D170)$$

go to D172

$$h_{G2} = 0.027 (12.k_{g2}/D_{e2}) (Re)_{rg2}^{0.8} (Pr)_{g2}^{1/3} (\mu_{g2}/\mu_{gi2})^{0.14} \quad (D171)$$

$$(K_G \cdot P'_{nc})_2 = h_{G2} (\rho_{g2} D_{i2}^2 / k_{g2}) ((Sc)_{g2} / (Pr)_{g2})^{1/3} \quad (D172)$$

If $((Re)_{L2} - 12,500.)$ D173, D173, D174

$$h_{L2} = 1.86 (12.k_L/D_{L2}) (Re)_{L2}^{1/3} (Pr)_{L2}^{1/3} (\mu_{L2}/\mu_{c2})^{0.14} \quad (D173)$$

go to D175

$$h_{L2} = 0.023 (12.k_L/D_{L2}) (Re)_{L2}^{0.8} (Pr)_{L2}^{0.4} \quad (D174)$$

$$P'_{nc2} = \frac{X_{v2} P_2 - P_{vi2}}{14.696 \ln \left(\frac{P_2 - P_{vi2}}{P_2 - X_{v2} P_2} \right)} \quad (D175)$$

$$K_{G2} = (K_G \cdot P'_{nc})_2 / P'_{nc2} \quad (D176)$$

$$(w_c/S_i)_2 = K_{G2} (X_{v2} P_2 - P_{vi2}) / 14.696 \quad (D177)$$

$$(q_g/S_i)_2 = h_{G2} (T_{g2} - T_{i2}) + (w_c/S_i)_2 \left(h_{fgc2} + C_{pL} (T_{i2} - T_{L2}) + \frac{V_{g2}^2 - V_{L2}^2}{2g_o J} \right) \quad (D178)$$

$$(q_L/S_i)_2 = h_{L2} (T_{i2} - T_{L2}) \quad (D179)$$

$$\Delta q_2 = (q_L/S_i)_2 - (q_g/S_i)_2 \quad (D180)$$

$$T_{i21} = T_{i22} \quad (D181)$$

$$\Delta q_{21} = \Delta q_{22} \quad (D182)$$

If (E-50.) D183, D183, D191

$$\text{If } \left| (T_{i2} - T_{i22}) / T_{i2} \right| < \epsilon_1 \text{ D191, D184, D184} \quad (D183)$$

$$T_{i22} = T_{i2} \quad (D184)$$

$$\Delta q_{22} = \Delta q_2 \quad (D185)$$

$$E = E + 1. \quad (D186)$$

If (E-2.) D187, D188, D188

$$T_{i2} = T_{i22} - \Delta q_{22} / (2 \cdot h_{L2}) \quad (D187)$$

go to D189

$$T_{i2} = (T_{i22} \Delta q_{21} - T_{i21} \Delta q_{22}) / (\Delta q_{21} - \Delta q_{22}) \quad (D188)$$

If $(T_{g2} - T_{i2})$ D190, D190, D105 (D189)

$$T_{i2} = T_{g2} - 0.1 \quad (D190)$$

go to D105

$$U_2 = (q_L / S_i)_2 / \Delta T_2 \quad (D191)$$

$$(w_c / S_i) = \frac{(w_c / S_i)_1 - (w_c / S_i)_2}{\ln \left(\frac{(w_c / S_i)_1}{(w_c / S_i)_2} \right)} \quad (D192)$$

$$(S_i)_{12} = (w_c)_{12} / (w_c / S_i) \quad (D193)$$

$$\bar{U} = Q_{12} / ((S_i)_{12} \Delta T_M) \quad (D194)$$

$$L_{12} = \left[\left(\frac{12 \cdot (S_i)_{12}}{\pi c_2 \frac{D_{L2} + D_{L1}}{2}} \right)^2 - \left(\frac{D_{L2} - D_{L1}}{2} \right)^2 \right]^{1/2} \quad (D195)$$

$$L_2 = L_1 + L_{12} \quad (D196)$$

$$\omega_2 = (w_L + w_{c2}) / w_{g2} \quad (D197)$$

$$\phi_2 = w_{v2} / w_{g2} \quad (D198)$$

$$\text{bulk temperature ratio} = T_{g2} / T_{L2} \quad (D199)$$

$$\text{phase velocity ratio} = V_{g2} / V_{L2} \quad (D200)$$

$$M_2 = V_{g2} / C_{g2} \quad (D201)$$

$$S_{i2} = S_{i1} + (S_i)_{12} \quad (D202)$$

$$Q_2 = Q_1 + Q_{12} \quad (D203)$$

We have now finished calculations for state 2. If we satisfy the following tests, the calculation is complete; if not, we reset several variables to establish state 1 as the beginning of the next mixing section interval and recalculate state 2.

$$\text{If } (T_{g2} - T_{L2}) \text{ D233, D233, D204}$$

$$\text{If } (w_{vo} - w_{c2}) \text{ D233, D233, D205} \quad (\text{D204})$$

$$\text{If } (T_{g2} - T_{L2} - \epsilon_6) \text{ D233, D233, D206} \quad (\text{D205})$$

$$h_{fgc1} = h_{fgc2} \quad (\text{D206})$$

$$C_{pv1} = C_{pv2} \quad (\text{D207})$$

$$C_{pnc1} = C_{pnc2} \quad (\text{D208})$$

$$C_{pg1} = C_{pg2} \quad (\text{D209})$$

$$P_1 = P_2 \quad (\text{D210})$$

$$(w_c / S_i)_1 = (w_c / S_i)_2 \quad (\text{D211})$$

$$w_{v1} = w_{v2} \quad (\text{D212})$$

$$w_{c1} = w_{c2} \quad (\text{D213})$$

$$w_{g1} = w_{g2} \quad (\text{D214})$$

$$T_{L1} = T_{L2} \quad (\text{D215})$$

$$T_{g1} = T_{g2} \quad (\text{D216})$$

$$T_{g1}(R) = T_{g2}(R) \quad (\text{D217})$$

$$T_{i1} = T_{i2} \quad (\text{D218})$$

$$V_{g1} = V_{g2} \quad (\text{D219})$$

$$V_{L1} = V_{L2} \quad (\text{D220})$$

$$V'_{g1} = V'_{g2} \quad (\text{D221})$$

$$V'_{L1} = V'_{L2} \quad (D222)$$

$$D_{L1} = D_{L2} \quad (D223)$$

$$L_1 = L_2 \quad (D224)$$

$$Q_1 = Q_2 \quad (D225)$$

$$(Re)_{g1} = (Re)_{g2} \quad (D226)$$

$$(Re)_{rg1} = (Re)_{rg2} \quad (D227)$$

$$A_{L1} = A_{L2} \quad (D228)$$

$$A_{g1} = A_{g2} \quad (D229)$$

$$S_{i1} = S_{i2} \quad (D230)$$

$$X_{v1} = X_{v2} \quad (D231)$$

$$\rho_{g1} = \rho_{g2} \quad (D232)$$

go to D82

read in data for next case (D233)

APPENDIX E

DERIVATION OF SOME BASIC CONSERVATION EQUATIONS

Continuity Equations:

In our mixing section analyses we assume that two flows enter the ejector. The secondary or liquid stream, w_L , and the primary or gas stream, w_{g0} , which may consist of a condensable vapor, w_{v0} , or a mixture of condensable vapor, w_{v0} , and a noncondensable gas, w_{nc} . The noncondensable flow rate, w_{nc} , remains constant throughout the mixing process, whereas the vapor flow rate generally decreases because of condensation. That portion of the vapor which condenses is defined as w_c . The total amount of condensed vapor at state 1 is defined as w_{c1} and the vapor which condenses between any two states 1 and 2, as $(w_c)_{12}$.

Thus, at state 1 we define the liquid flow

$$w_{L1} = w_L + w_{c1} \quad (E1)$$

and the gas flow

$$w_{g1} = w_{v1} + w_{nc} \quad (E2)$$

At state 2 the liquid flow becomes

$$w_{L2} = w_{L1} + (w_c)_{12} \quad (E3)$$

and the gas flow

$$w_{g2} = w_{g1} - (w_c)_{12} \quad (E4)$$

Also, the total condensed vapor at state 2 is

$$w_{c2} = w_{c1} + (w_c)_{12} \quad (E5)$$

For the present mixing section analyses, multiple liquid jets may be assumed. In this case we distribute the liquid flow evenly between the jets and assume that condensation occurs equally on each jet at any given state. If we let c_2 equal the number of liquid jets, then the liquid jet diameter becomes at state 1

$$D_{L1} = \left(\frac{4 \cdot A_{L1}}{\pi c_2} \right)^{1/2} \quad (E6)$$

where the total flow area for liquid, A_{L1} is

$$A_{L1} = \frac{144}{3600} \left(\frac{w_L}{\rho_L V_{L1}} + \frac{w_{c1}}{\rho_{c1} V_{L1}} \right) \quad (E7)$$

The flow area for the gas mixture is

$$A_{g1} = \frac{144}{3600} \left(\frac{w_{g1}}{\rho_{g1} V_{g1}} \right) \quad (E8)$$

and the diameter of the mixing section becomes

$$D_{g1} = \left(\frac{4 \cdot (A_{g1} + A_{L1})}{\pi} \right)^{1/2} \quad (E9)$$

Thus, for any given state in the mixing section, we define the total flow area as being

$$A = A_L + A_g \quad (E10)$$

Momentum Equations, Constant Pressure Mixing:

With reference to Figure 27a, the conservation of linear momentum for the liquid jet control volume yields

$$p_1 A_{L1} + \frac{3600 \cdot w_{L1} V_{L1}}{g'} + F_i + F_m + F'_m = p_2 A_{L2} + \frac{3600 \cdot w_{L2} A_{L2}}{g'} + \frac{p_1 + p_2}{2} (A_{L1} - A_{L2}) \quad (E11)$$

where we assume a linear pressure variation in the mixing section and have neglected any angle effects on the force along the sides of the control volume.

From Figure 27b the conservation of linear momentum for the gas mixture control volume yields

$$p_1 A_{g1} + \frac{3600 \cdot w_{g1} V_{g1}}{g'} + \frac{p_1 + p_2}{2} (A_{L1} - A_{L2}) = p_2 A_{g2} + \frac{3600 \cdot w_{g2} V_{g2}}{g'} + F_w + F_i + F_m + \frac{(p_1 + p_2) (A_1 - A_2)}{2} \quad (E12)$$

Referring to Figure 28, the total relative velocity between the bulk gas mixture and the bulk liquid stream, v_r , is

$$V_r = V_g - V_L \quad (E13)$$

also,

$$V_r = V'_g + V'_L \quad (E14)$$

where V'_g is the relative velocity between the bulk gas mixture and the liquid jet surface, or phase interface, and V'_L is the relative velocity between the phase interface and the bulk liquid jet. To calculate the relative velocities V'_g and V'_L at any state, we proceed as follows. From shear stress at the phase interface we get

$$\tau_g + \tau_m = \tau_L \quad (E15)$$

where τ_m is shear stress due to momentum exchange across the interface and τ_g and τ_L are shear stresses due to friction at the interface.

Since

$$\tau_m = \frac{3600 \cdot \left(\frac{w_c}{S_i} \right) V'_g}{g'} \quad (E16)$$

and from Reference 20

$$\tau_g = \frac{(f_i)_g \rho_g V'^2_g 3600^2}{2 \cdot g'} \quad (E17)$$

$$\tau_L = \frac{(f_i)_L \rho_L V'^2_L 3600^2}{2 \cdot g'} \quad (E18)$$

where the Fanning friction factors, $(f_i)_g$ and $(f_i)_L$ are calculated from equation E33 (streamline flow) and equation E35 (turbulent flow), and the Reynolds numbers are

$$(Re)_{rg} = \frac{3600.}{12.} \left(\frac{\rho_g V'_g D_e}{\mu_g} \right) \quad (E19)$$

to calculate $(f_i)_g$ and

$$(Re)_L = \frac{3600.}{12.} \left(\frac{\rho_L V'_L D_L}{\mu_L} \right) \quad (E20)$$

to calculate $(f_i)_L$, we may solve equations E15-E20 for V'_L with the result

$$V'_L = \left(\frac{(f_i)_g}{(f_i)_L} \left(\frac{\rho_g}{\rho_L} \right) V'_g{}^2 + \frac{2 \cdot g' \tau_m}{(f_i)_L \rho_L 3600.{}^2} \right)^{1/2} \quad (E21)$$

and from equation E14

$$V'_g = V_r - V'_L \quad (E22)$$

Having determined the relative velocities V'_L and V'_g , we may now calculate the following resultant shear forces from,

momentum exchange from the bulk gas mixture to the phase interface

$$F_m = 3600. (w_c)_{12} \bar{V}'_g / g' \quad (E23)$$

momentum exchange from the phase interface to the liquid jet

$$F'_m = 3600. (w_c)_{12} \bar{V}'_L / g' \quad (E24)$$

wall friction

$$F_w = \left(\frac{\bar{f}_w \bar{\rho}_g \bar{V}'_g{}^2 3600.{}^2}{2 \cdot g'} \right) (S_w)_{12} \quad (E25)$$

and phase interface friction

$$F_i = \left(\frac{\bar{f}_i \bar{\rho}_g \bar{V}'_g{}^2 3600.{}^2}{2 \cdot g'} \right) (S_i)_{12} \quad (E26)$$

Equations E25 and E26 are approximations of the friction forces in the x-direction given by

$$F_w = \int_1^2 \pi \tau_w D_g dL \cos \beta \quad (E27)$$

and

$$F_i = \int_1^2 \pi \tau_i D_L dL \cos \gamma \quad (E28)$$

where we have assumed steady, one-dimensional flow, and uniform pressure across sections 1 and 2. For purposes of the present calculations we also assume that the half-angles, β and γ , are small. Thus, we may rewrite equations E27 and E28 as

$$F_w \approx \tau_w (S_w)_{12} \quad (E29)$$

and

$$F_i \approx \tau_i (S_i)_{12} \quad (E30)$$

In accordance with McAdams (Reference 20) we define the shear stress as

$$\tau = \frac{f \rho V^2}{2} \frac{3600.}{g} \quad (E31)$$

and we estimate friction factors (Reference 20) as follows:

streamline flow: ($Re \leq 1000$)

$$f_w = 16. / (Re)_g \quad (E32)$$

$$f_i = 16. / (Re)_{rg} \quad (E33)$$

turbulent flow: ($Re > 1000.$)

$$f_w = 0.0014 + \left(0.125 / (Re)_g^{0.32} \right) \quad (E34)$$

$$f_i = 0.0014 + \left(0.125 / (Re)_{rg}^{0.32} \right) \quad (E35)$$

The mixing section wall friction factor is based on the bulk gas mixture Reynolds number

$$(Re)_g = \frac{\rho_g V_g D_e}{12. \mu_g} \quad (E36)$$

In the constant pressure mixing section analyses for Analytical Models I and IIa, where from constant pressure

$$P = P_1 = P_2 \quad (\text{E37})$$

we can solve equation E11 for the liquid jet velocity

$$V_{L2} = \frac{3600. w_{L1} V_{L1} + g' (F_m + F_i + F'_m)}{3600. w_{L2}} \quad (\text{E38})$$

and combining equations E10 and E12 we can solve for the bulk gas mixture velocity

$$V_{g2} = \frac{3600. w_{g1} V_{g1} - g' (F_m + F_i + F'_w)}{3600. w_{g2}} \quad (\text{E39})$$

In the constant pressure mixing section analysis for Analytical Model IIb where we have simplified the relative velocity to the expression in equation E13, equation E38 becomes

$$V_{L2} = \frac{3600. w_{L1} V_{L1} + g' (F_m + F_i)}{3600. w_{L2}} \quad (\text{E40})$$

and the shear forces, F_m and F_i , are evaluated as follows:

$$F_m = 3600. (w_c)_{12} \bar{V}_r / g' \quad (\text{E41})$$

$$F_i = \left(\frac{\bar{f}_i \bar{\rho}_g \bar{V}_r 3600.^2}{2. g'} \right) (S_i)_{12} \quad (\text{E42})$$

where the average friction factor, \bar{f}_i , is evaluated on the basis of the Reynolds number, $(\text{Re})_{rg}$, given by equation E36 and redefined as

$$(\text{Re})_{rg} = \frac{\rho_g V_r D_e 3600.}{12. \mu_g} \quad (\text{E43})$$

Momentum Equations, Constant Area Mixing:

In the mixing section analysis for Analytical Model III where we assume that the mixing section remains at constant area

$$A_1 = A_2 \quad (E44)$$

we solve equation E11 for the liquid jet velocity

$$V_{L2} = \left[g'(p_1 A_{L1} - p_2 A_{L2}) + 3600 \cdot w_{L1} V_{L1} + g'(F_m + F_i + F'_m) - \frac{p_1 + p_2}{2} (A_{L1} - A_{L2}) g' \right] / (3600 \cdot w_{L2}) \quad (E45)$$

and the bulk gas mixture velocity from equation E11

$$V_g = \frac{144}{3600} \left(\frac{w_g}{\rho_g A_g} \right) \quad (E46)$$

and the total static pressure in the mixing section from equations E12 and E44

$$p_2 = p_1 + \frac{3600 \cdot (w_{g1} V_{g1} - w_{g2} V_{g2}) - g' (F_m + F_i + F'_w)}{g' \left(\frac{A_{L1} - A_{L2}}{2} + A_{g2} \right)} \quad (E47)$$

The resultant shear forces, F_m , F'_m , F_w and F_i are evaluated from equations E23, D24, E25 and E26 respectively.

Energy Equations:

The steady flow energy equation for the control volume represented by Figure 29 may be written as

$$w_{g1} \left(h_{g1} + \frac{V_{g1}^2}{2 \cdot g_o J} \right) + w_{L1} \left(h_{L1} + \frac{V_{L1}^2}{2 \cdot g_o J} \right) = w_{g2} \left(h_{g2} + \frac{V_{g2}^2}{2 \cdot g_o J} \right) + w_{L2} \left(h_{L2} + \frac{V_{L2}^2}{2 \cdot g_o J} \right) \quad (E48)$$

Since from equations E4 and E3,

$$w_{g1} = w_{g2} + (w_c)_{12} \quad (E49)$$

and

$$w_{L2} = w_{L1} + (w_c)_{12} \quad (E3)$$

by combining equations E48, E49, and E3 we rewrite the energy equation as

$$w_{g2} \left(h_{g1} - h_{g2} + \frac{V_{g1}^2 - V_{g2}^2}{2 \cdot g_o J} \right) + (w_c)_{12} \left(h_{v1} - h_{L2} + \frac{V_{g1}^2 - V_{L2}^2}{2 \cdot g_o J} \right) + w_{L1} \left(h_{L1} - h_{L2} + \frac{V_{L1}^2 - V_{L2}^2}{2 \cdot g_o J} \right) = 0. \quad (E50)$$

Assuming that

$$h_{L1} - h_{L2} \approx C_{pL} (T_{L1} - T_{L2}) + \frac{144.}{\rho_L J} (p_1 - p_2) \quad (E51)$$

and substituting equation E51 into E50 and solving for T_{L2} , our energy equation now becomes

$$T_{L2} = T_{L1} + \frac{1.}{w_{L1} C_{pL}} \left[w_{g2} \left(h_{g1} - h_{g2} + \frac{V_{g1}^2 - V_{g2}^2}{2 \cdot g_o J} \right) + (w_c)_{12} \left(h_{v1} - h_{L2} + \frac{V_{g1}^2 - V_{L2}^2}{2 \cdot g_o J} \right) + w_{L1} \left(\frac{V_{L1}^2 - V_{L2}^2}{2 \cdot g_o J} + \frac{144.}{\rho_L J} (p_1 - p_2) \right) \right] \quad (E52)$$

Now for the mixing section interval in Figure 29 we define the following individual heat transfer rates.

$(q_{nc})_{12}$, the heat transfer rate from the noncondensable

$$(q_{nc})_{12} = w_{nc} \left(C_{pnc1} T_{g1}(R) - C_{pnc2} T_{g2}(R) + \frac{V_{g1}^2 - V_{g2}^2}{2 \cdot g_o J} \right) \quad (E53)$$

$(q_v)_{12}$, the heat transfer rate from the vapor which does not condense

$$(q_v)_{12} = w_{v2} \left(C_{pv1} T_{g1}(R) - C_{pv2} T_{g2}(R) + \frac{V_{g1}^2 - V_{g2}^2}{2 \cdot g_o J} \right) \quad (E54)$$

$(q_c)_{12}$, the heat transfer rate from the vapor which condenses

$$(q_c)_{12} = (w_c)_{12} \left(\frac{(C_{pv1} + C_{pv2})(T_{g1} + T_{g2} - T_{i1} - T_{i2}) + h_{fg}(T_{i1}) + h_{fg}(T_{i2})}{2} \right. \\ \left. + C_{pL} \left(\frac{T_{i1} + T_{i2}}{2} - T_{L2} \right) + \frac{V_{g1}^2 - V_{L2}^2}{2 \cdot g_o J} \right) \quad (E55)$$

$(q_L)_{12}$, the heat transfer rate from the liquid jet

$$(q_L)_{12} = w_{L1} \left(\frac{V_{L1}^2 - V_{L2}^2}{2 \cdot g_o J} + \frac{144}{\rho_L J} (p_1 - p_2) \right) \quad (E56)$$

and the total heat transfer rate for the interval 1-2 as

$$Q_{12} = (q_{nc})_{12} + (q_v)_{12} + (q_c)_{12} + (q_L)_{12} \quad (E57)$$

Substituting equation E57 into equation E52 yields

$$T_{L2} = T_{L1} + \frac{Q_{12}}{w_{L1} C_{pL}} \quad (E58)$$

For the constant pressure mixing section analyses, Analytical Models I, IIa, and IIb the pressure term in equation E56 drops out to yield

$$(q_L)_{12} = w_{L1} \left(\frac{v_{L1}^2 - v_{12}^2}{2 \cdot g_o J} \right) \quad (E59)$$

For Analytical Model I where $w_{nc} = 0.$, equation E53 is deleted and equation E57 becomes

$$Q_{12} = (q_v)_{12} + (q_c)_{12} + (q_L)_{12} \quad (E60)$$

APPENDIX F

SOURCES OF DATA AND CORRELATIONS

Sources of data for property calculations and of correlations for heat and mass transfer calculations used in the mixing section analyses are given below.

Property Calculation Parameters:

A. Water Vapor

1. Lennard-Jones force constants

a. molecular potential well depth, $(\epsilon/k)_v$, 356. K

b. molecular collision diameter, σ_v , 2.649 Å

Table 8-2, p. 270, Reference 24.

c. measure of molecular polarity, t^* , 1.2

Table 3.10-1, p. 214, Reference 23.

2. Sutherland constant, S'_v , 559.74 K

equation 7-19, Reference 24.

B. Carbon Dioxide Gas

1. Lennard-Jones force constants

a. molecular potential well depth, $(\epsilon/k)_{nc}$, 213. K

b. molecular collision diameter, σ_{nc} , 3.996 Å

Table I-A, p. 1111, Reference 23.

c. molecular polarizability, α , 0.265×10^{-23}

Table 13.2 - 3, p. 950, Reference 23.

2. Sutherland constant, S'_{nc} , 233. K

equation 7-19, Reference 24 (revised to agree with available viscosity data).

Fanning Friction Factors:

Mixing section wall and phase interface friction are both estimated from correlations for fluid friction in pipes based on isothermal fluid flow.

A. Streamline flow, $Re \leq 1000$.

$$f = 16. / Re \quad (F1)$$

equation 3.46, Reference 19

equation 6-5a, Reference 20

B. Turbulent flow, $Re > 1000$. (Smooth wall)

$$f = 0.0014 + \frac{0.125}{Re^{0.32}} \quad (F2)$$

equation 3.47e, Reference 19

equation 6.8, Reference 20

For purposes of the mixing section calculations, a smooth transition from streamline to turbulent flow was assumed at $Re = 1000$.

Heat Transfer Correlations:

A. Annular gas stream

1. Streamline flow, $(Re)_{rg} \leq 9000$.

$$h_G = 1.86 \left(\frac{12. k_g}{D_e} \right) (Re)_{rg}^{1/3} (Pr)_g^{1/3} \left(\frac{\mu_g}{\mu_{gi}} \right)^{0.14} \quad (F3)$$

equation 6.1, Reference 19

equation 9-28a, Reference 20

2. Turbulent flow $(Re)_{rg} > 9000$.

$$h_G = 0.027 \left(\frac{12. k_g}{D_e} \right) (Re)_{rg}^{0.8} (Pr)^{1/3} \left(\frac{\mu_g}{\mu_{gi}} \right)^{0.14} \quad (F4)$$

equation 6.3, Reference 19

B. Liquid Jet

1. Streamline flow, $(Re)_L \leq 12,500$.

$$h_L = 1.86 \left(\frac{12 \cdot k_L}{D_L} \right) (Re)_L^{1/3} (Pr)_L^{1/3} \left(\frac{\mu_L}{\mu_c} \right)^{0.14} \quad (F6)$$

equation 6.1, Reference 19

equation 9-28a, Reference 20

2. Turbulent flow, $(Re)_L > 12,500$.

$$h_L = 0.023 \left(\frac{12 \cdot k_L}{D_L} \right) (Re)_L^{0.8} (Pr)^{0.4} \quad (F7)$$

equation 9-10a, Reference 20

It has been assumed for these calculations that the heat transfer coefficients, h_G and h_L , for streamline flow are independent of the term L/D appearing in the correlations given by the references. Also, to suit the calculations, the transition points from streamline to turbulent flow are taken as $(Re)_{rg} = 9000$. for the gas stream and $(Re)_L = 12,500$. for the liquid jet.

Mass Transfer Correlation:

$$(K_G \cdot P'_{nc}) = h_G \left(\frac{\rho_g D'}{k_g} \right) \left(\frac{(Sc)_g}{(Pr)_g} \right)^{1/3} \quad (F8)$$

equation 13.29, Reference 19.

APPENDIX G

IDENTIFICATION OF SUBROUTINES USED IN COMPUTATIONAL PROCEDURES

Several Fortran subroutines used in the computer calculations and which appear in the computational procedures of Appendices B, C and D are described briefly below.

SATP:

Description - steam and water property calculation to determine saturation pressure corresponding to a given temperature.

Input - temperature, T	F
10	50
20	68
30	86
40	104
50	122
60	140
70	158
80	176
90	194
100	212

Output - pressure, p psia

Limits - pressure is given by equations 11 and 12 of the reference.

Reference - Reference 21.

SATT:

Description - steam and water property calculation to determine saturation temperature corresponding to a given pressure.

Input - pressure, p psia

estimated temperature, T F

Output - temperature, T_{sat}	F
100	212
110	230
120	248
130	266
140	284
150	302
160	320
170	338
180	356
190	374
200	392
210	410
220	428
230	446
240	464
250	482
260	500
270	518
280	536
290	554
300	572
310	590
320	608
330	626
340	644
350	662
360	680
370	698
380	716
390	734
400	752
410	770
420	788
430	806
440	824
450	842
460	860
470	878
480	896
490	914
500	932
510	950
520	968
530	986
540	1004
550	1022
560	1040
570	1058
580	1076
590	1094
600	1112
610	1130
620	1148
630	1166
640	1184
650	1202
660	1220
670	1238
680	1256
690	1274
700	1292
710	1310
720	1328
730	1346
740	1364
750	1382
760	1400
770	1418
780	1436
790	1454
800	1472
810	1490
820	1508
830	1526
840	1544
850	1562
860	1580
870	1598
880	1616
890	1634
900	1652
910	1670
920	1688
930	1706
940	1724
950	1742
960	1760
970	1778
980	1796
990	1814
1000	1832

Limits - trial and error calculation with pressure given by equations 11 and 12 of the reference. Specified accuracy for solution derived from two consecutive calculations is $\frac{P_2 - P_1}{P_1} < 0.0001$.

Reference - Reference 21.

VAPTP:

Description - steam and water property calculation to determine enthalpy, entropy, and specific volume of vapor at a given temperature and pressure.

Input - temperature, T	F
pressure, p	psia
Output - enthalpy, h_g	Btu/lbm
entropy, s_g	Btu/lbm-F
specific volume, v_g	ft ³ /lbm

Limits - specific volume, enthalpy, and entropy are given by equations 13, 14 and 16A of the reference.

Reference - Reference 21.

SATLQ:

Description - steam and water property calculation to determine enthalpy, entropy, and specific volume of saturated liquid at a given temperature.

Input - temperature, T	F
Output - enthalpy, h_f	Btu/lbm
entropy, s_f	Btu/lbm-F
specific volume, v_f	ft ³ /lbm

Limits - enthalpy and entropy are polynomial approximations based on the tabulated values of the reference between the temperature limits 50-350 F. Specific volume is given by equation 18 of the reference.

Reference - Reference 21.

SATHFG:

Description - steam and water property calculation to determine saturated vapor enthalpy and saturated liquid enthalpy at a given saturated temperature and pressure condition.

Input - temperature, T	F
pressure, p	psia
Output - vapor enthalpy, h_g	Btu/lbm
liquid enthalpy, h_f	Btu/lbm

Limits - liquid enthalpy is a polynomial approximation based on the tabular values of the reference between the temperature limits 50-350 F. Vapor enthalpy is given by equation 14 of the reference.

Reference - Reference 21.

SATLQV:

Description - steam and water property calculation to determine specific volume of saturated liquid at a given temperature.

Input - temperature, T	F
Output - specific volume, v_f	ft ³ /lbm

Limits - specific volume is given by equation 18 of the reference.

Reference - Reference 21.

SUPHT1:

Description - steam and water property calculation to determine a superheated vapor temperature at a given pressure and vapor entropy.

Input - temperature, T (estimated)	F
pressure, p	psia
entropy, s_g	Btu/lbm-F

Input - temperature, T	Output - temperature, T	F
10	10	0.0000
20	20	0.0000
30	30	0.0000
40	40	0.0000
50	50	0.0000
60	60	0.0000
70	70	0.0000
80	80	0.0000
90	90	0.0000
100	100	0.0000
110	110	0.0000
120	120	0.0000
130	130	0.0000
140	140	0.0000
150	150	0.0000
160	160	0.0000
170	170	0.0000
180	180	0.0000
190	190	0.0000
200	200	0.0000
210	210	0.0000
220	220	0.0000
230	230	0.0000
240	240	0.0000
250	250	0.0000
260	260	0.0000
270	270	0.0000
280	280	0.0000
290	290	0.0000
300	300	0.0000
310	310	0.0000
320	320	0.0000
330	330	0.0000
340	340	0.0000
350	350	0.0000
360	360	0.0000
370	370	0.0000
380	380	0.0000
390	390	0.0000
400	400	0.0000
410	410	0.0000
420	420	0.0000
430	430	0.0000
440	440	0.0000
450	450	0.0000
460	460	0.0000
470	470	0.0000
480	480	0.0000
490	490	0.0000
500	500	0.0000
510	510	0.0000
520	520	0.0000
530	530	0.0000
540	540	0.0000
550	550	0.0000
560	560	0.0000
570	570	0.0000
580	580	0.0000
590	590	0.0000
600	600	0.0000
610	610	0.0000
620	620	0.0000
630	630	0.0000
640	640	0.0000
650	650	0.0000
660	660	0.0000
670	670	0.0000
680	680	0.0000
690	690	0.0000
700	700	0.0000
710	710	0.0000
720	720	0.0000
730	730	0.0000
740	740	0.0000
750	750	0.0000
760	760	0.0000
770	770	0.0000
780	780	0.0000
790	790	0.0000
800	800	0.0000
810	810	0.0000
820	820	0.0000
830	830	0.0000
840	840	0.0000
850	850	0.0000
860	860	0.0000
870	870	0.0000
880	880	0.0000
890	890	0.0000
900	900	0.0000
910	910	0.0000
920	920	0.0000
930	930	0.0000
940	940	0.0000
950	950	0.0000
960	960	0.0000
970	970	0.0000
980	980	0.0000
990	990	0.0000
1000	1000	0.0000

Limits - trial and error calculation with entropy given by equation 16A of reference. Specified accuracy for solution derived from two consecutive calculation is $\frac{s_2 - s_1}{s_1} < 0.0001$.

Reference - Reference 21.

SUPHT2:

Description - steam and water property calculation to determine a superheated vapor temperature at a given pressure and vapor enthalpy.

Input - temperature, T (estimated)	F
pressure, p	psia
enthalpy, h_g	Btu/lbm
Output - temperature, T	F

Limits - trial and error calculation with enthalpy given by equation 14 of reference. Specified accuracy for solution derived from two consecutive calculations is $\frac{h_2 - h_1}{h_1} < 0.0001$.

Reference - Reference 21.

VISLIQ:

Description - calculation to determine viscosity of water at a given temperature.

Input - temperature, T	F
Output, viscosity, μ_L	lbm/hr-ft

Limits - tabular values from 32 to 212 F and equation are given on p. 374 of reference.

Reference - Reference 22.

VAP:

Description - calculation to determine density viscosity, ratio of specific heats, and specific heat at constant pressure of water vapor at a given temperature and pressure.

Input - temperature, T	F
temperature, T	K
pressure, p	psia
molecular potential well depth, $(\epsilon/k)_v$	K
molecular weight, W_v	lbm/lbm-mole
molecular collision diameter, σ_v	Å
universal gas constant, R'	Btu/lbm-mole-R

Output - density, ρ_g	lbm/ft ³
viscosity, μ_g	lbm/hr-ft
ratio of specific heats, K_g	
specific heat at constant pressure, C_{pg}	Btu/lbm-R

Limits - specific volume is given by equation 13 of Reference 21.

Specific heat at constant pressure is given by Table 170, p. 220 of Reference 22 for the temperature range 300-2500 K. Viscosity is given by equation 8.2-18 of Reference 23. Collision integrals are approximated from Table I-M of Reference 23.

References - specific volume, Reference 21

specific heat at constant pressure, Reference 22

viscosity, Reference 23.

GASP:

Description - calculation to determine specific heat at constant pressure and ratio of specific heats of a carbon dioxide gas and water vapor mixture at a given temperature and known flow rates.

Input - temperature, T	K
noncondensable flow rate, w_{nc}	lbm/hr
condensable flow rate, w_v	lbm/hr
noncondensable molecular weight, W_{nc}	lbm/lbm-mole
condensable molecular weight, W_v	lbm/lbm-mole
universal gas constant, R'	Btu/lbm-mole-R

Output - specific heat at constant pressure of the gas mixture, C_{pg}	Btu/lbm-R
ratio of specific heats of the gas mixture, K_g	

Limits - specific heat at constant pressure of carbon dioxide gas and water vapor given by Table 170, p. 220 of the reference. Temperature range for gas is 273-1200 K, and for the vapor is 300-2500 K.

Reference - Reference 22.

GASPl:

Description - gas and vapor mixture property calculation to determine gas mixture molecular collision diameter, binary diffusion coefficient, condensable viscosity, noncondensable viscosity, and gas mixture viscosity for a given temperature and condensable mole fraction.

Input - temperature, T	K
noncondensable molecular collision diameter, σ_{nc}	\AA
condensable molecular collision diameter, σ_v	\AA
property calculation parameter, α	
property calculation parameter, t^*	
condensable molecular potential well depth, $(\epsilon/k)_v$	K
noncondensable molecular potential well depth, $(\epsilon/k)_{nc}$	K
noncondensable molecular weight, W_{nc}	lbm/lbm-mole
condensable molecular weight, W_v	lbm/lbm-mole
pressure, p	psia
condensable mole fraction, X_v	
Output - gas mixture molecular collision diameter, σ_g	\AA
binary diffusion coefficient, D'	ft^2/hr
condensable viscosity, μ_v	lbm/hr-ft
noncondensable viscosity, μ_{nc}	lbm/hr-ft
gas mixture viscosity, μ_g	lbm/hr-ft

Limits - individual gas mixture component viscosities are given by equation 8.2-18 of Reference 23. Gas mixture viscosity is given by equation 8.2-30 of Reference 23. The binary diffusion coefficient is given by equation 8.2-44 of Reference 23. Molecular collision diameter and molecular potential well depth of the mixture are given by equations 8.6-3, 8.6-4 and 8.6-5 of Reference 23. Collision integrals are approximated from Table I-M of Reference 23.

Reference - Reference 23.

GASP2:

Description - carbon dioxide gas and water vapor mixture property calculation to determine density, thermal conductivity and specific heat at constant pressure for the gas mixture, noncondensable specific heat at constant pressure, and condensable specific heat at constant pressure for a given temperature, pressure, and condensable mole fraction.

Input - pressure, p	psia
condensable mole fraction, X_v	
noncondensable molecular weight, W_{nc}	lbm/lbm-mole
condensable molecular weight, W_v	lbm/lbm-mole
universal gas constant, R'	Btu/lbm-mole-R
temperature, T	R
temperature, T	K
noncondensable viscosity, μ_{nc}	lbm/hr-ft
condensable viscosity, μ_v	lbm/hr-ft
noncondensable Sutherland constant, S'_{nc}	K
condensable Sutherland constant, S'_v	K
gas mixture molecular collision diameter, σ_g	Å
Output - gas mixture density, ρ_g	lbm/ft ³
gas mixture thermal conductivity, k_g	Btu/hr-ft-F
gas mixture specific heat at constant pressure, C_{pg}	Btu/lbm-R
noncondensable specific heat at constant pressure, C_{pnc}	Btu/lbm-R
condensable specific heat at constant pressure, C_{pv}	Btu/lbm-R

Limits - specific heat at constant pressure of carbon dioxide gas and water vapor given by Table 170, p. 220 of Reference 23. Temperature range for gas is 273-1200 K, and for the vapor is 300-2500 K. Thermal conductivity of binary mixture is given by equation 7-17 of Reference 24.

References - specific heat at constant pressure, Reference 23.

gas mixture thermal conductivity, Reference 24.

GASP3:

Description - gas and vapor mixture property calculation to determine viscosity of mixture at a given temperature and condensable mole fraction.

Input - temperature, T	K
noncondensable molecular collision diameter, σ_{nc}	\AA
condensable molecular collision diameter, σ_v	\AA
property calculation parameter, α	
property calculation parameter, t^*	
condensable molecular potential well depth, $(\epsilon/k)_v$	K
noncondensable molecular potential well depth, $(\epsilon/k)_{nc}$	K
noncondensable molecular weight, W_{nc}	lbm/lbm-mole
condensable molecular weight, W_v	lbm/lbm-mole
total static pressure, p	psia
partial pressure of vapor, p_v	psia
Output - gas mixture viscosity, μ_g	lbm/hr-ft

Limits - individual gas mixture component viscosities are given by equation 8.2-18 of Reference 23. Gas mixture viscosity is given by equation 8.2-30 of Reference 23. The binary diffusion coefficient is given by equation 8.2-44 of Reference 23. Molecular collision diameter and molecular potential well depth of the mixture are given by equations 8.6-3, 8.6-4 and 8.6-5 of Reference 23. Collision integrals are approximated from Table I-M of Reference 23.

Reference - Reference 23.

GASP4:

Description - Calculation to determine viscosity of vapor at a given temperature.

Input - temperature, T	K
condensable molecular collision diameter, σ_v	Å
condensable molecular potential well depth, $(\epsilon/k)_v$	K
condensable molecular weight, W_v	lbm/lbm-mole

Output - viscosity, μ_v lbm/hr-ft

Limits - viscosity is given by equation 8.2-18 of Reference 23. Collision integrals are approximated from Table I-M of Reference 23.

Reference - Reference 23.

FORCE:

Description - calculation to determine phase interface resultant friction force and mixing section wall resultant friction force for a given mixing section and liquid jet geometry and known Reynolds numbers.

Input - average liquid jet diameter, \bar{D}_L	in.
average mixing section diameter, \bar{D}_g	in.
mixing section length, L_{12}	in.
+ average bulk liquid velocity, \bar{V}_L	ft/sec
average bulk gas velocity, \bar{V}_g	ft/sec
+ average relative velocity, \bar{V}'_g	ft/sec
liquid jet surface area, $(S_i)_{12}$	ft ²
bulk gas Reynolds number at state 1, $(Re)_{g1}$	
bulk gas Reynolds number at state 2, $(Re)_{g2}$	

+ For mixing section Analytical Models I, IIa and III the phase interface friction shear stress is based on the relative velocity, \bar{V}'_g , and for Analytical Model IIb it is based on the velocity $(\bar{V}_g - \bar{V}_L)$.

Reynolds number of annular gas stream
at state 1, $(Re)_{rg1}$

Reynolds number of annular gas stream
at state 2, $(Re)_{rg2}$

gas density at state 1, ρ_{g1} lbm/ft³

gas density at state 2, ρ_{g2} lbm/ft³

Output - phase interface resultant friction
force, F_i lbf

mixing section wall resultant friction
force, F_w lbf

References - friction factors, f_i and f_w , from equations E32-E35.

Shear stress from equation E31. Shear forces from equations E29 and
E30.

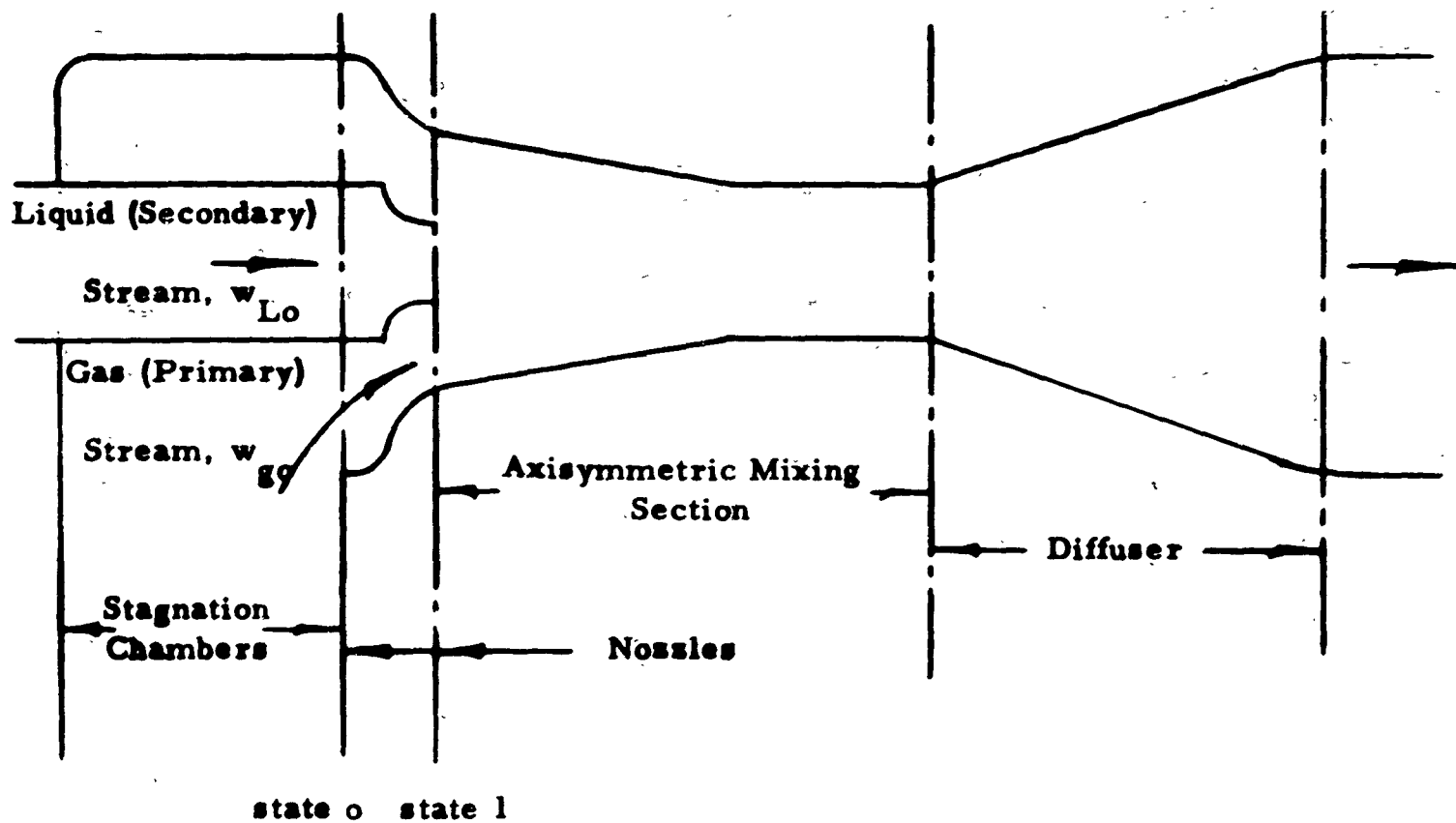


FIGURE 1 - SCHEMATIC OF CONDENSING EJECTOR

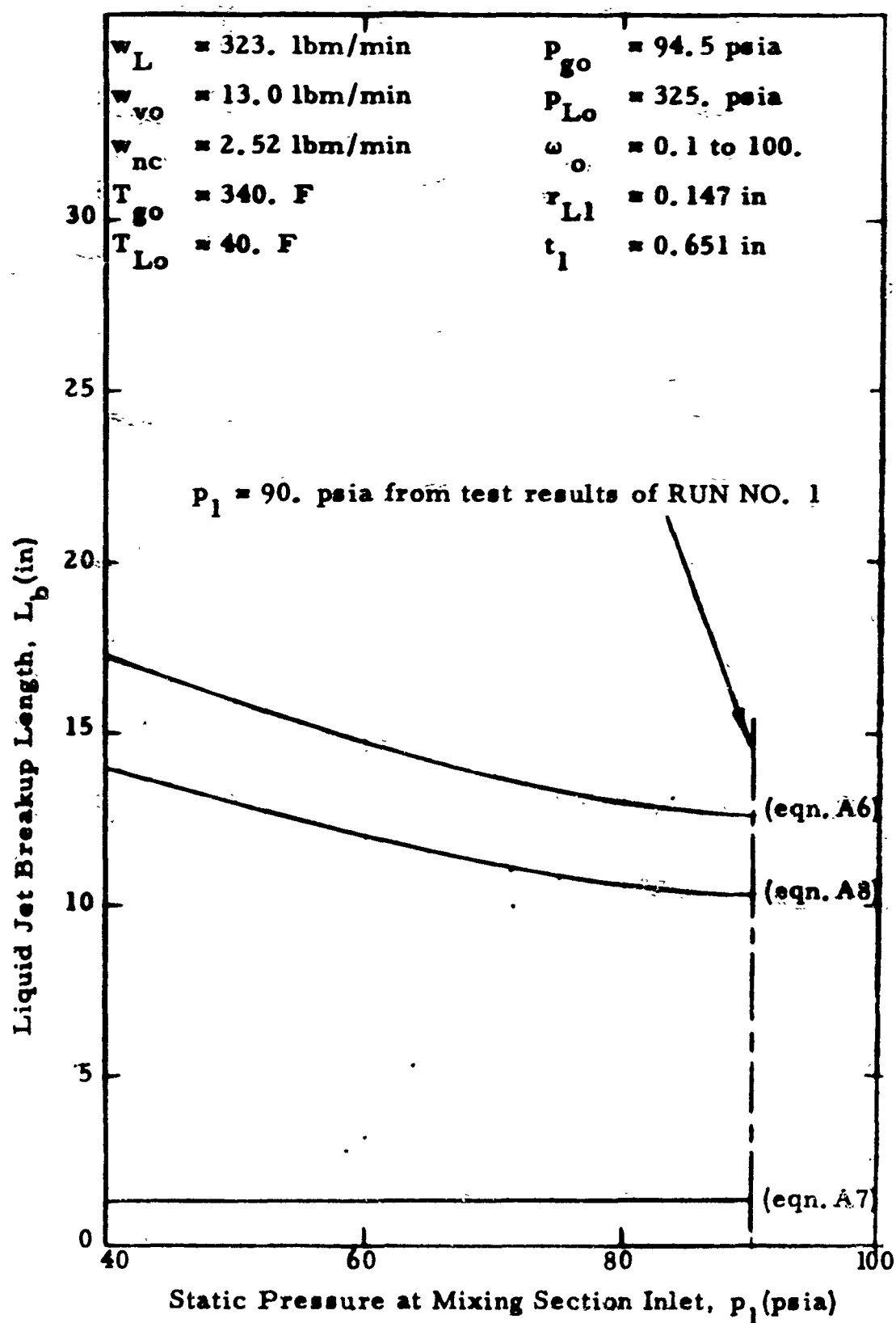


FIGURE 2 - LIQUID JET BREAKUP LENGTH VERSUS
 STATIC PRESSURE AT MIXING SECTION INLET -
 NONCONDENSABLE CASE

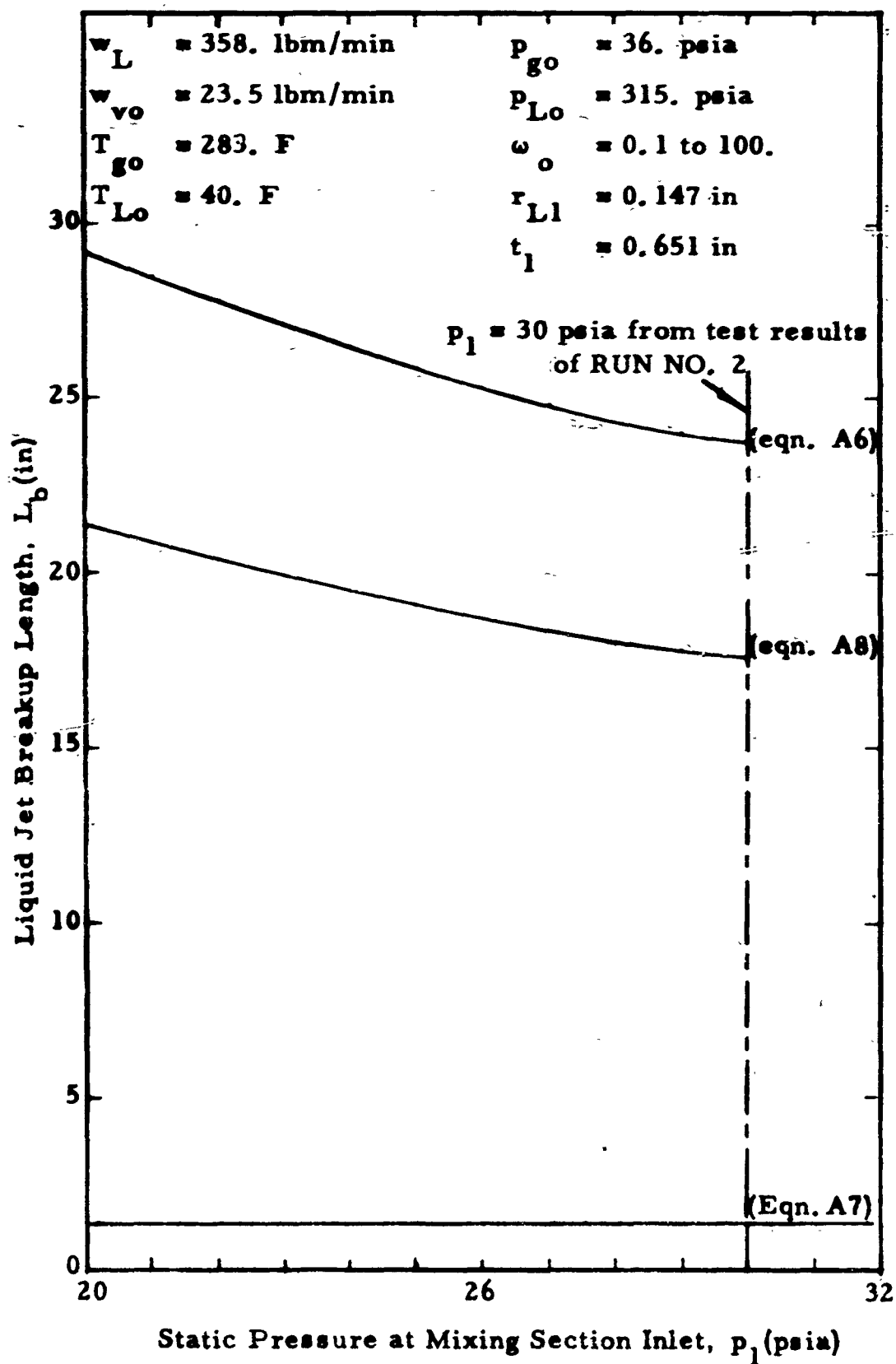
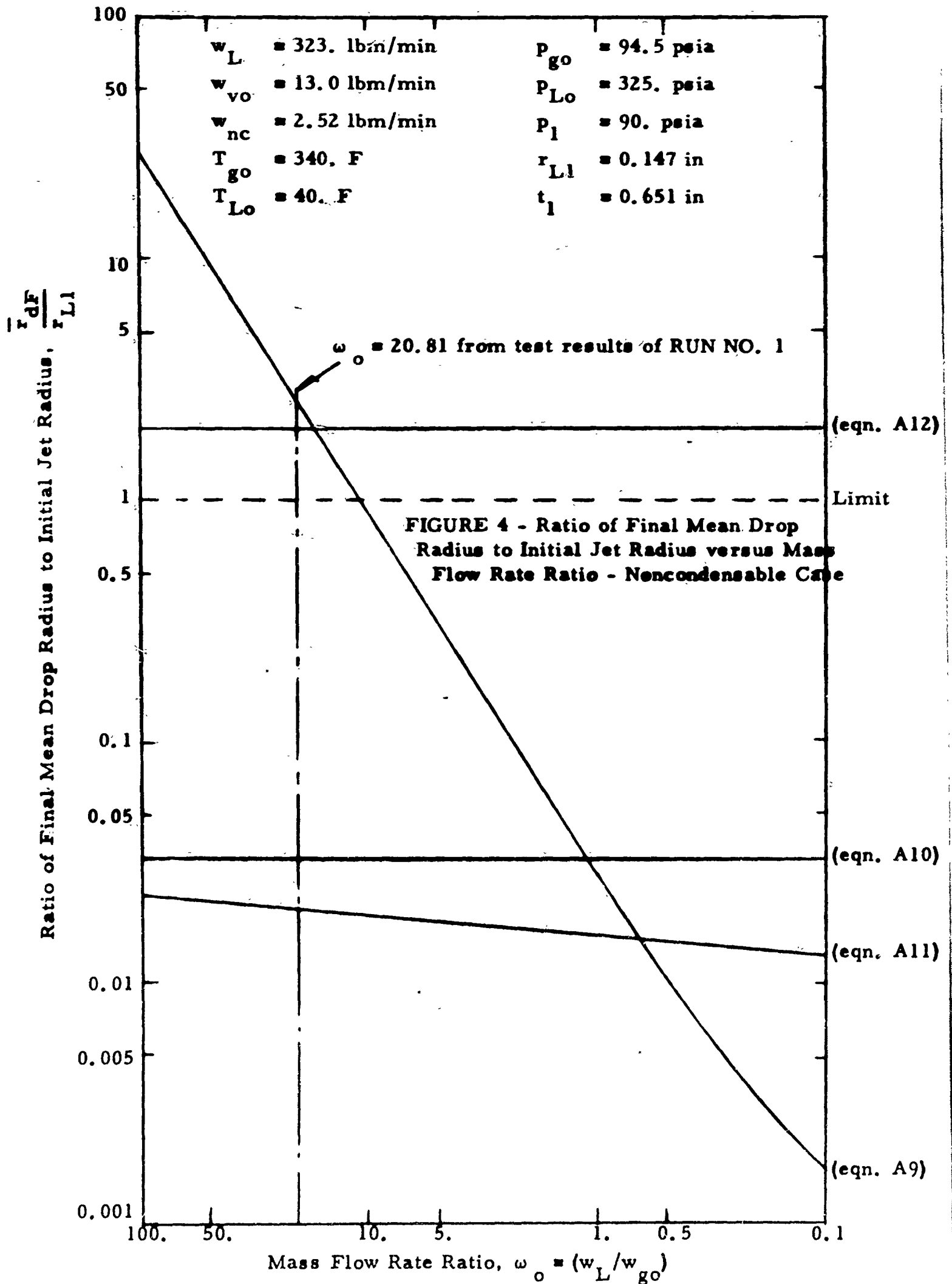
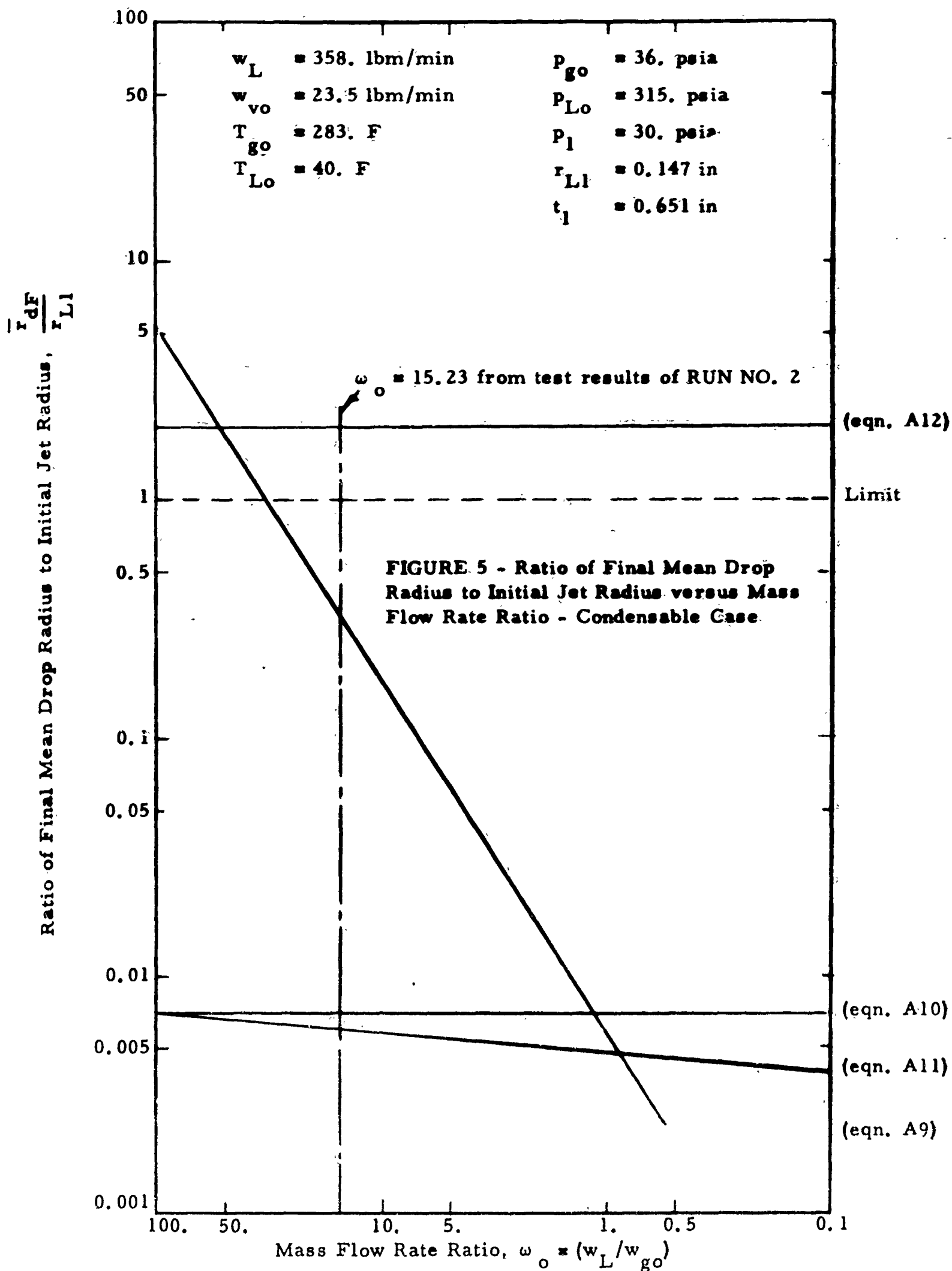
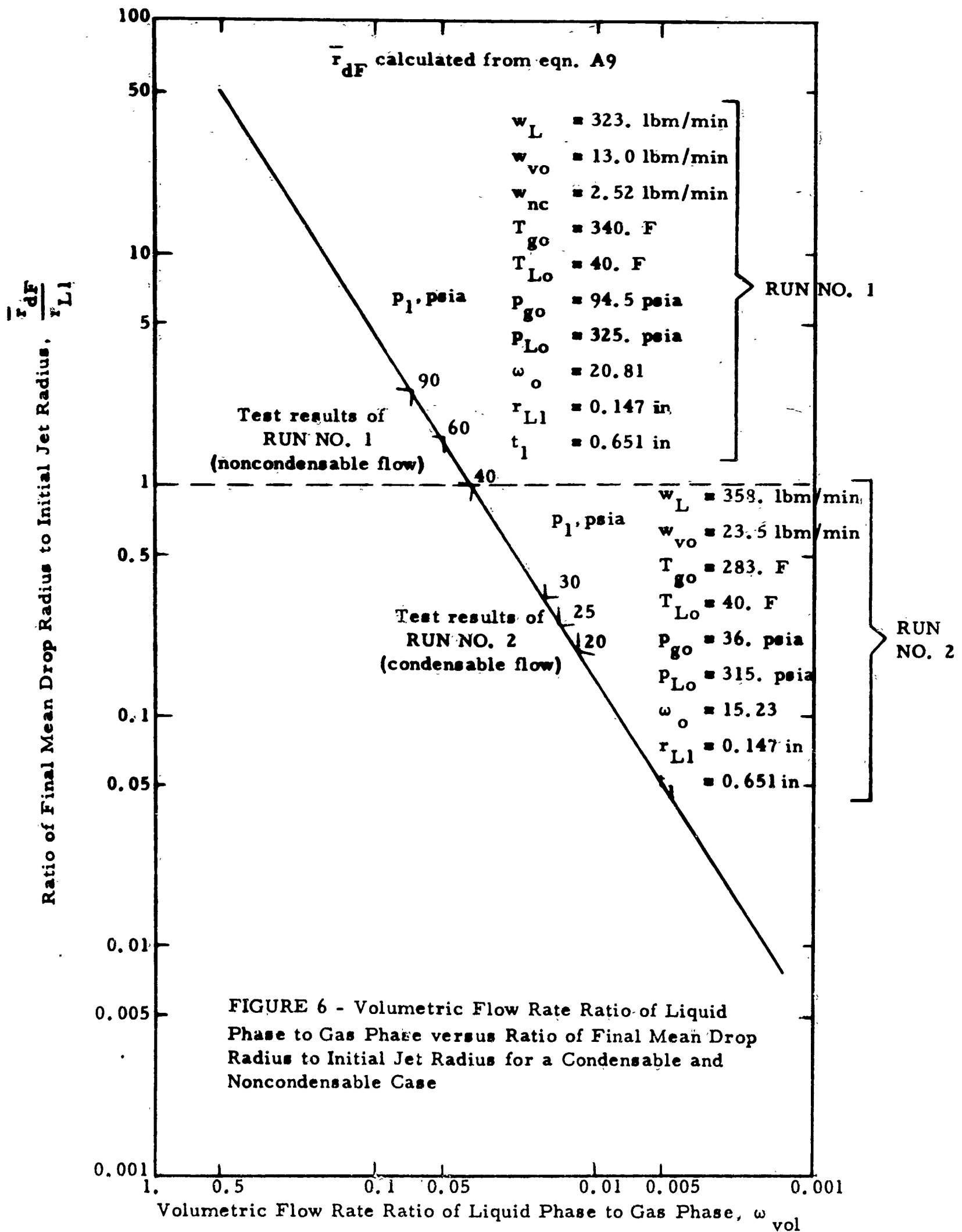


FIGURE 3 - LIQUID JET BREAKUP LENGTH VERSUS
 STATIC PRESSURE AT MIXING SECTION INLET -
 CONDENSABLE CASE







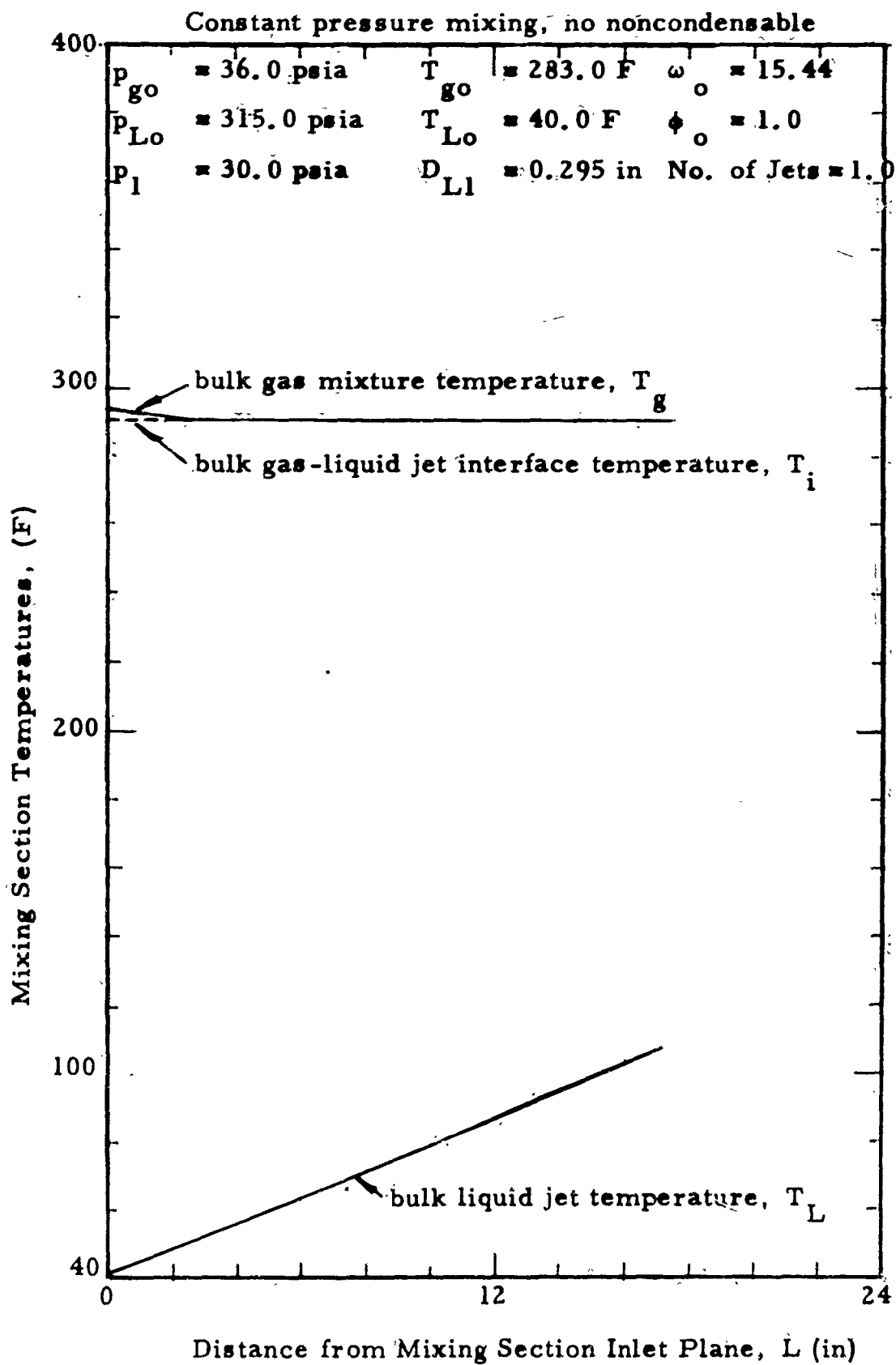


FIGURE 7 - VARIOUS MIXING SECTION TEMPERATURES
VERSUS DISTANCE FROM MIXING SECTION INLET
PLANE - MODEL I

$P_{go} = 36.0 \text{ psia}$ $T_{go} = 283.0 \text{ F}$ $\omega_o = 15.44$
 $P_{Lo} = 315.0 \text{ psia}$ $T_{Lo} = 40.0 \text{ F}$ $\phi_o = 1.0$
 $D_{L1} = 0.295 \text{ in}$ $p_1 = 30.0 \text{ psia}$ No. of Jets = 1.0

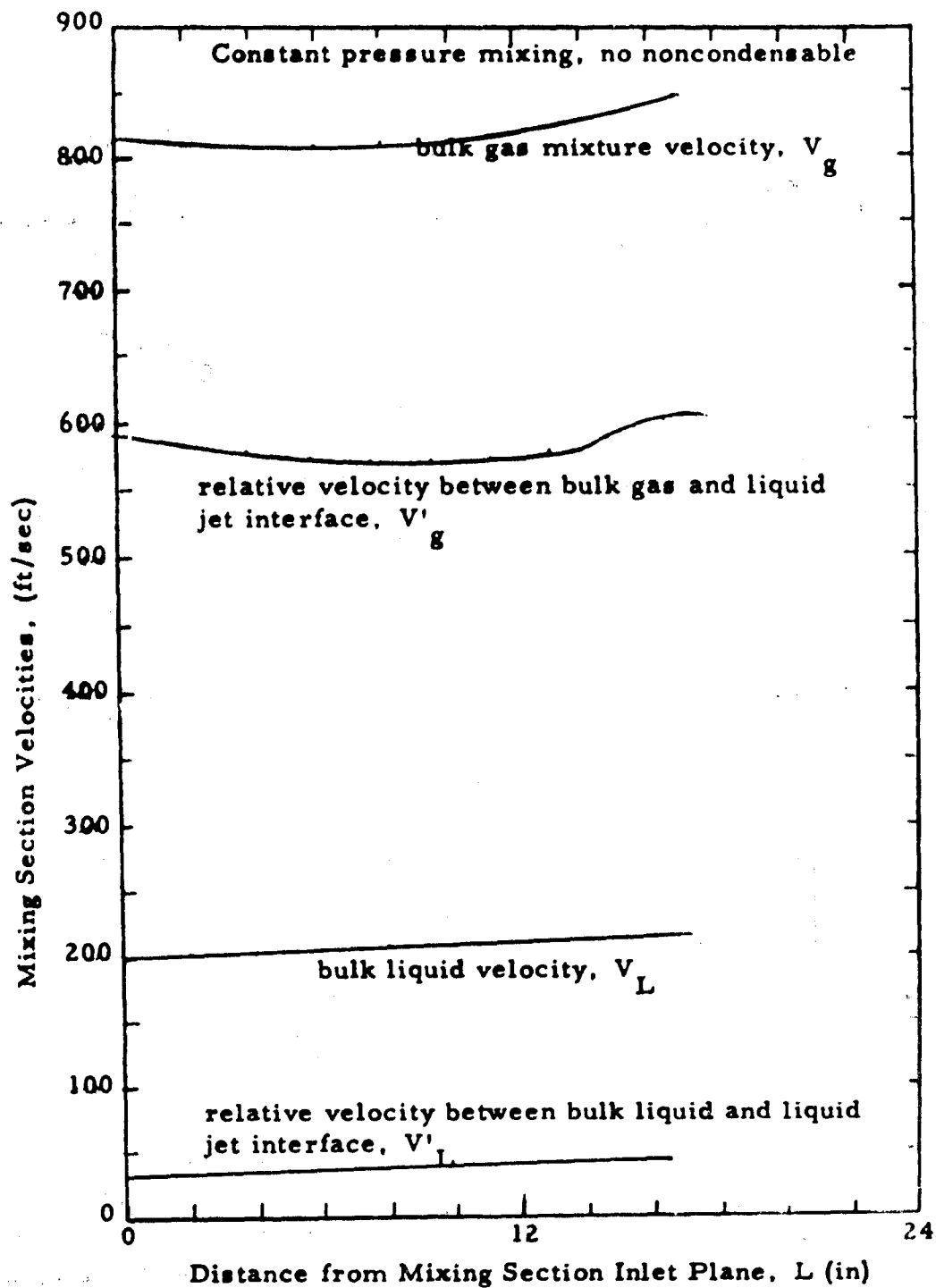


FIGURE 8 - VARIOUS MIXING SECTION VELOCITIES VERSUS DISTANCE FROM MIXING SECTION INLET PLANE - MODEL I

$$p_{go} = 36.0 \text{ psia}$$

$$D_{L1} = 0.295 \text{ in}$$

$$\omega_o = 15.44$$

$$p_{Lo} = 315.0 \text{ psia}$$

$$T_{go} = 283.0 \text{ F}$$

$$\phi_o = 1.0$$

$$p_l = 30.0 \text{ psia}$$

$$T_{Lo} = 40.0 \text{ F}$$

$$\text{No. of Jets} = 1.0$$

Constant pressure mixing, no noncondensable

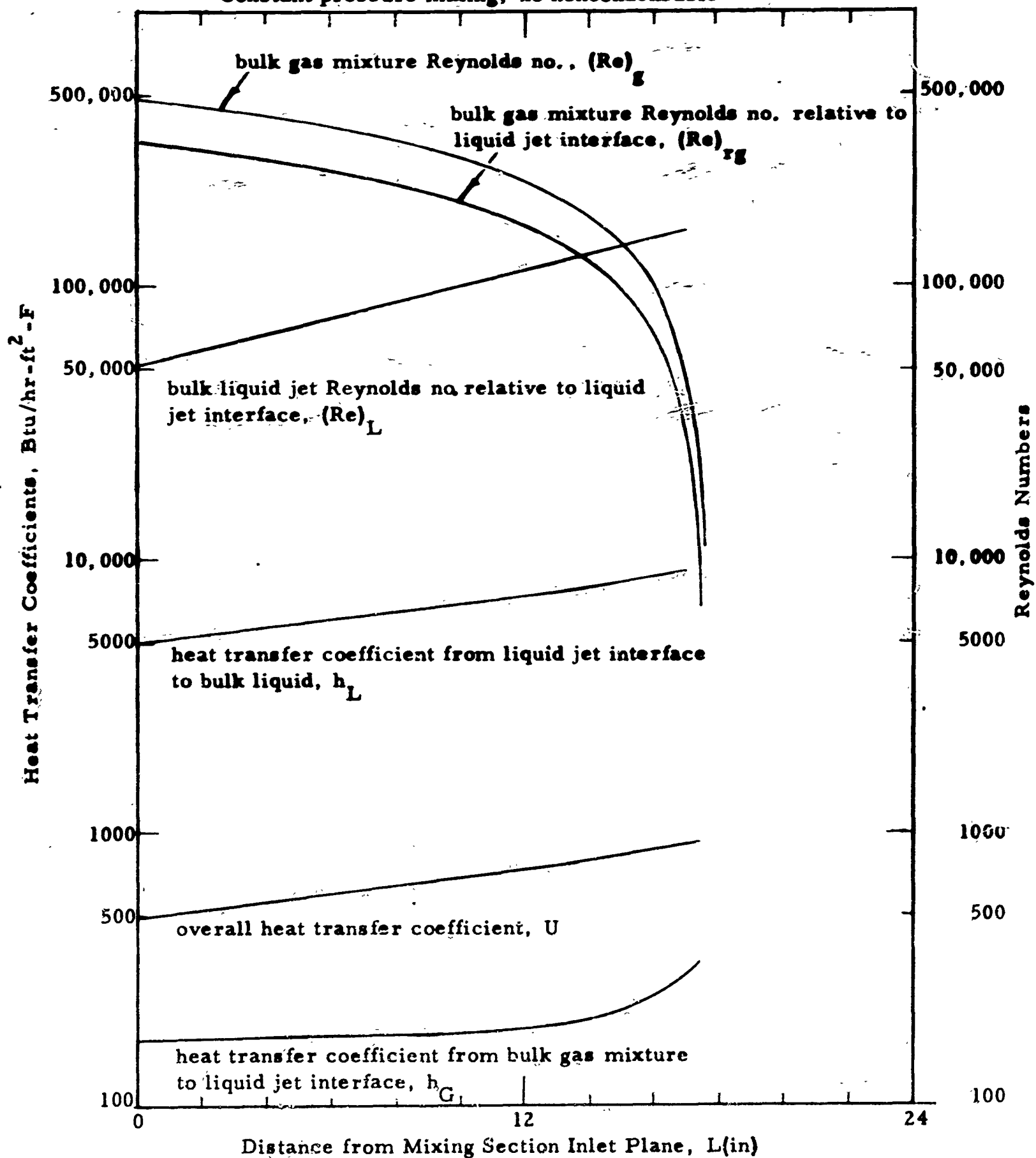


FIGURE 9 - VARIOUS REYNOLDS NUMBERS AND HEAT TRANSFER COEFFICIENTS VERSUS DISTANCE FROM MIXING SECTION INLET PLANE - MODEL I

$p_{go} = 36.0$ psia	$D_{L1} = 0.295$ in	$\omega_o = 15.44$
$p_{Lo} = 315.0$ psia	$T_{go} = 283.0$ F	$\phi_o = 1.0$
$p_1 = 30.0$ psia	$T_{Lo} = 40.0$ F	No. of Jets = 1.0

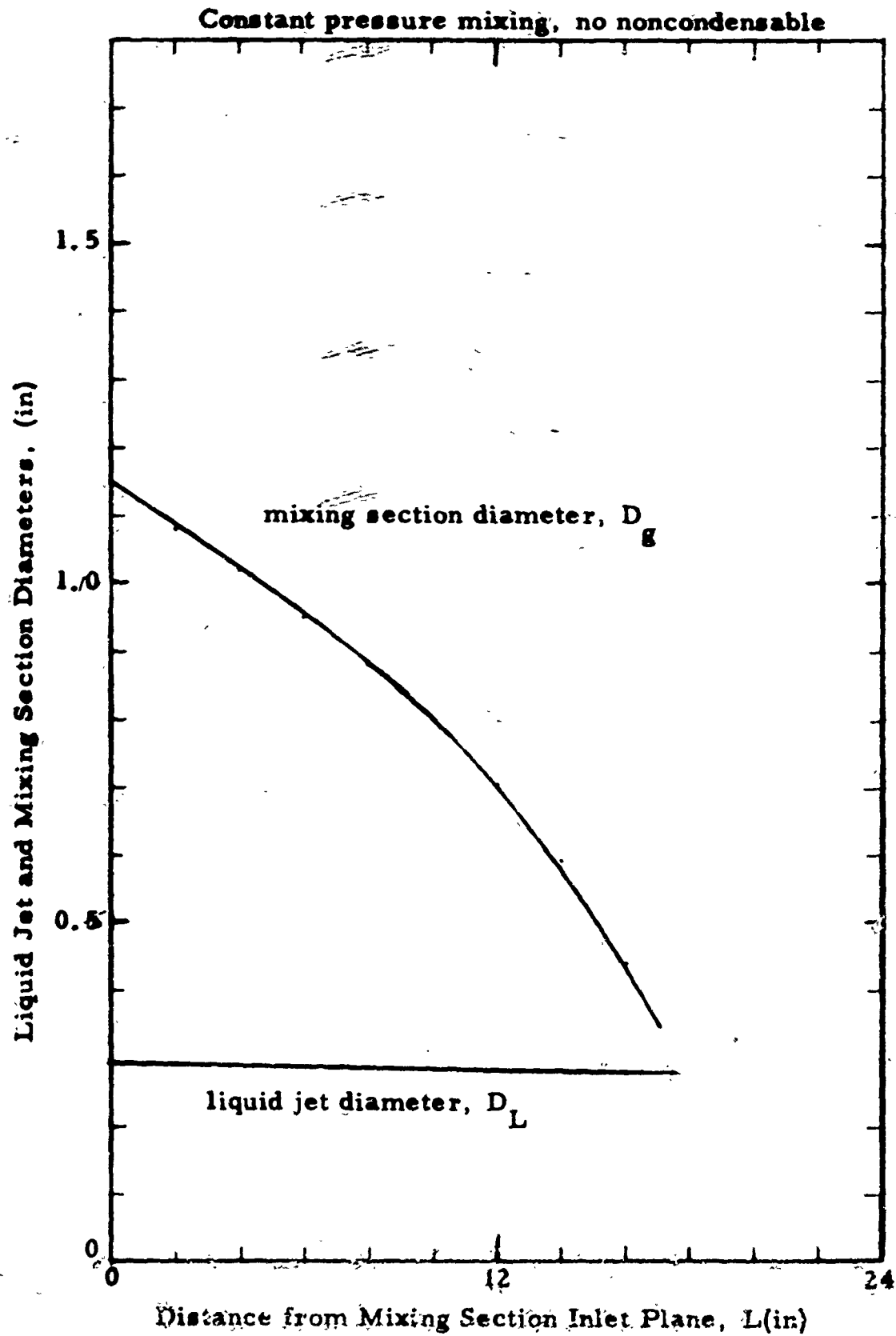


FIGURE 10 - LIQUID JET AND MIXING SECTION DIAMETERS VERSUS DISTANCE FROM MIXING SECTION INLET PLANE - MODEL I

$P_{go} = 94.5 \text{ psia}$	$D_{L1} = 0.295 \text{ in}$	$\omega_o = 21.24$
$P_{Lo} = 325.0 \text{ psia}$	$T_{go} = 340.0 \text{ F}$	$\phi_o = 0.838$
$P_1 = 90.0 \text{ psia}$	$T_{Lo} = 40.0 \text{ F}$	No. of Jets = 1.0

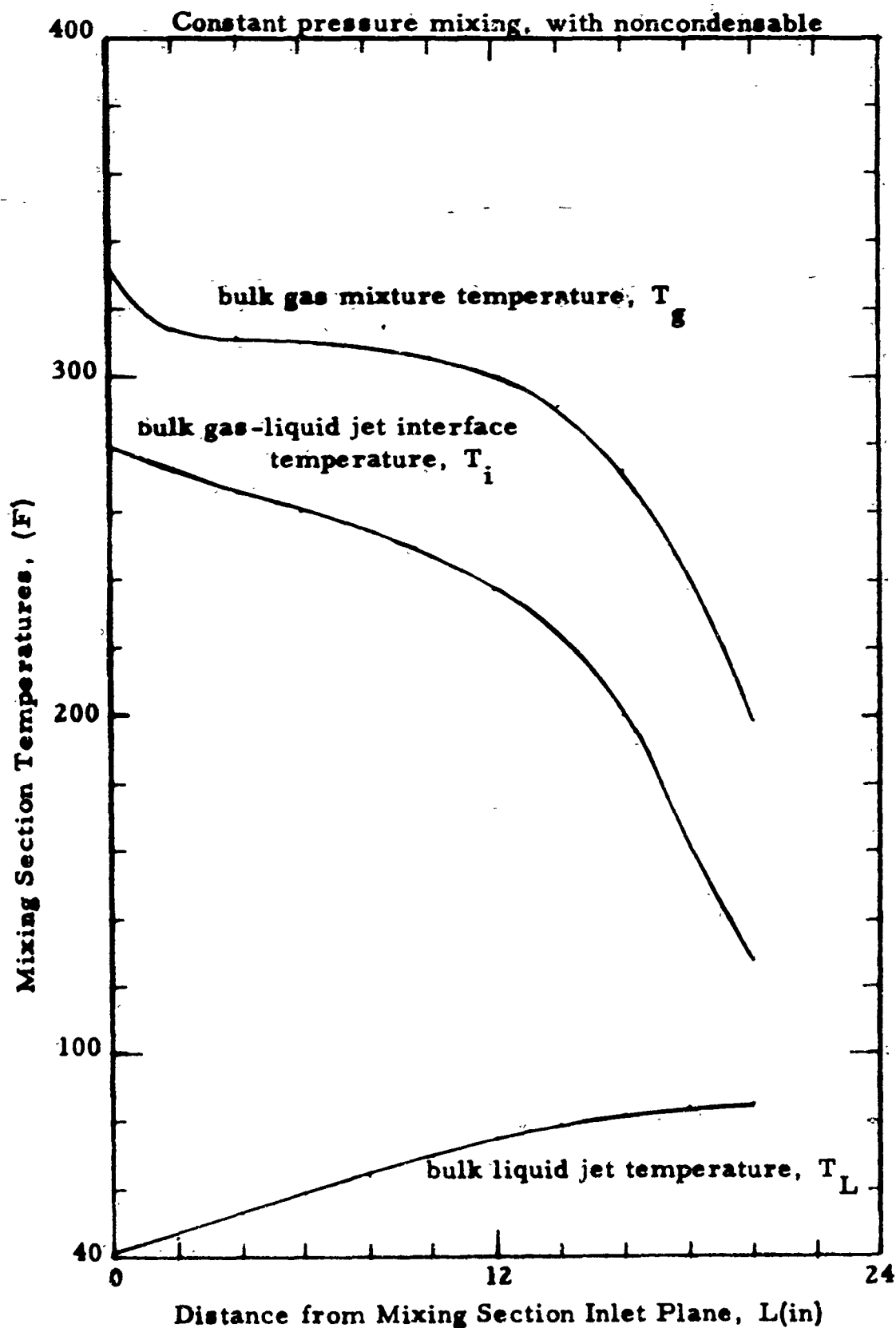


FIGURE 11 - VARIOUS MIXING SECTION TEMPERATURES
VERSUS DISTANCE FROM MIXING SECTION INLET PLANE -
MODEL IIa

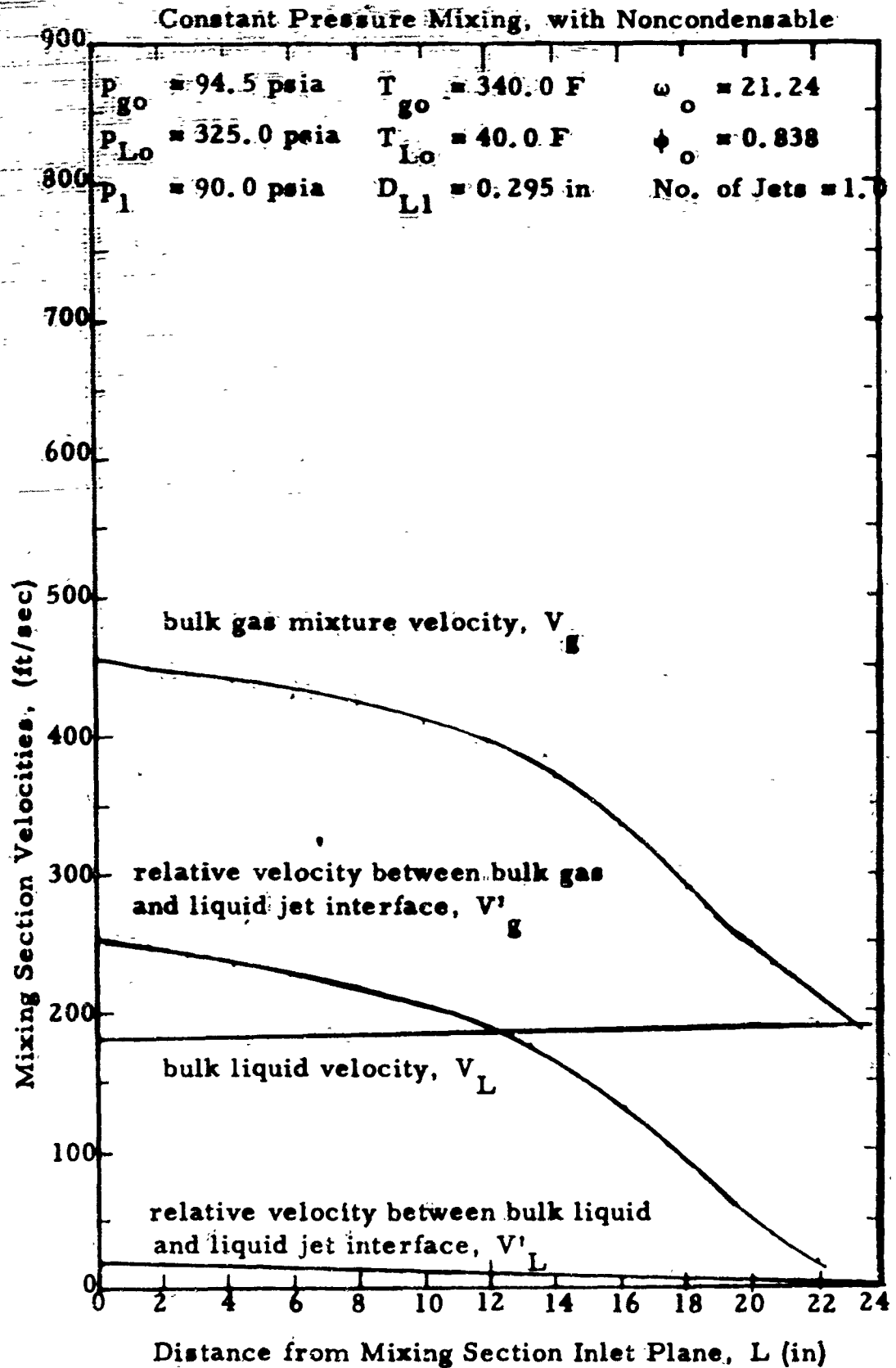


FIGURE 12 - VARIOUS MIXING SECTION VELOCITIES
VERSUS DISTANCE FROM MIXING SECTION INLET
PLANE - MODEL IIa

$p_{go} = 94.5 \text{ psia}$	$T_{go} = 340.0 \text{ F}$	$\omega_o = 21.24$
$p_{Lo} = 325.0 \text{ psia}$	$T_{Lo} = 40.0 \text{ F}$	$\phi_o = 0.838$
$p_1 = 90.0 \text{ psia}$	$D_{L1} = 0.295 \text{ in}$	No. of Jets = 1.0

Constant pressure mixing, with noncondensable

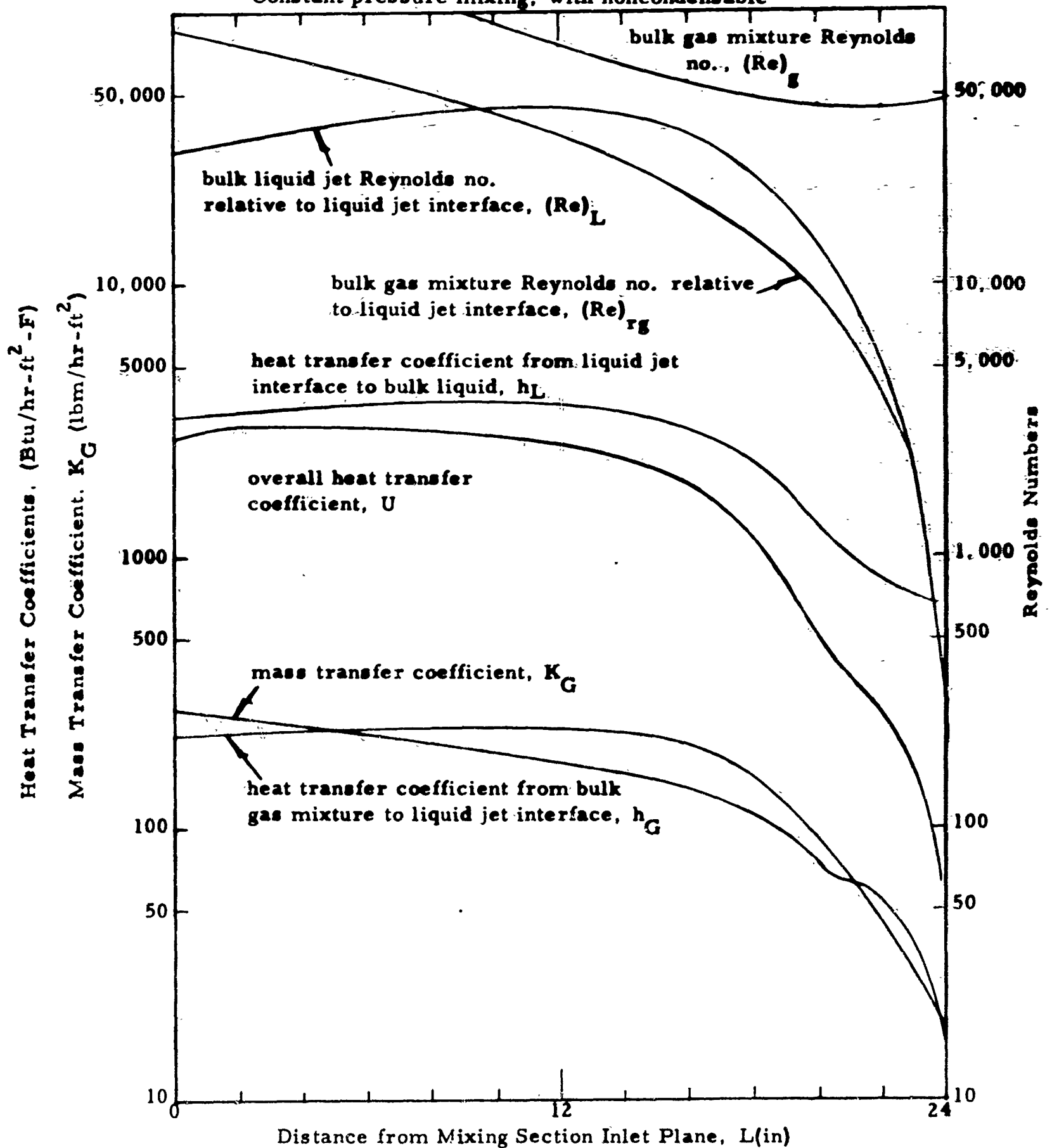


FIGURE 13 - VARIOUS REYNOLDS NUMBERS, HEAT TRANSFER COEFFICIENTS, AND MASS TRANSFER COEFFICIENT VERSUS DISTANCE FROM MIXING SECTION INLET PLANE - MODEL IIa

P_{go}	$= 94.5$ psia	T_{go}	$= 340.0$ F	ω_o	$= 21.24$
P_{Lo}	$= 325.0$ psia	T_{Lo}	$= 40.0$ F	ϕ_o	$= 0.838$
P_l	$= 90.0$ psia	D_{L1}	$= 0.295$ in	No. of Jets $= 1.0$	

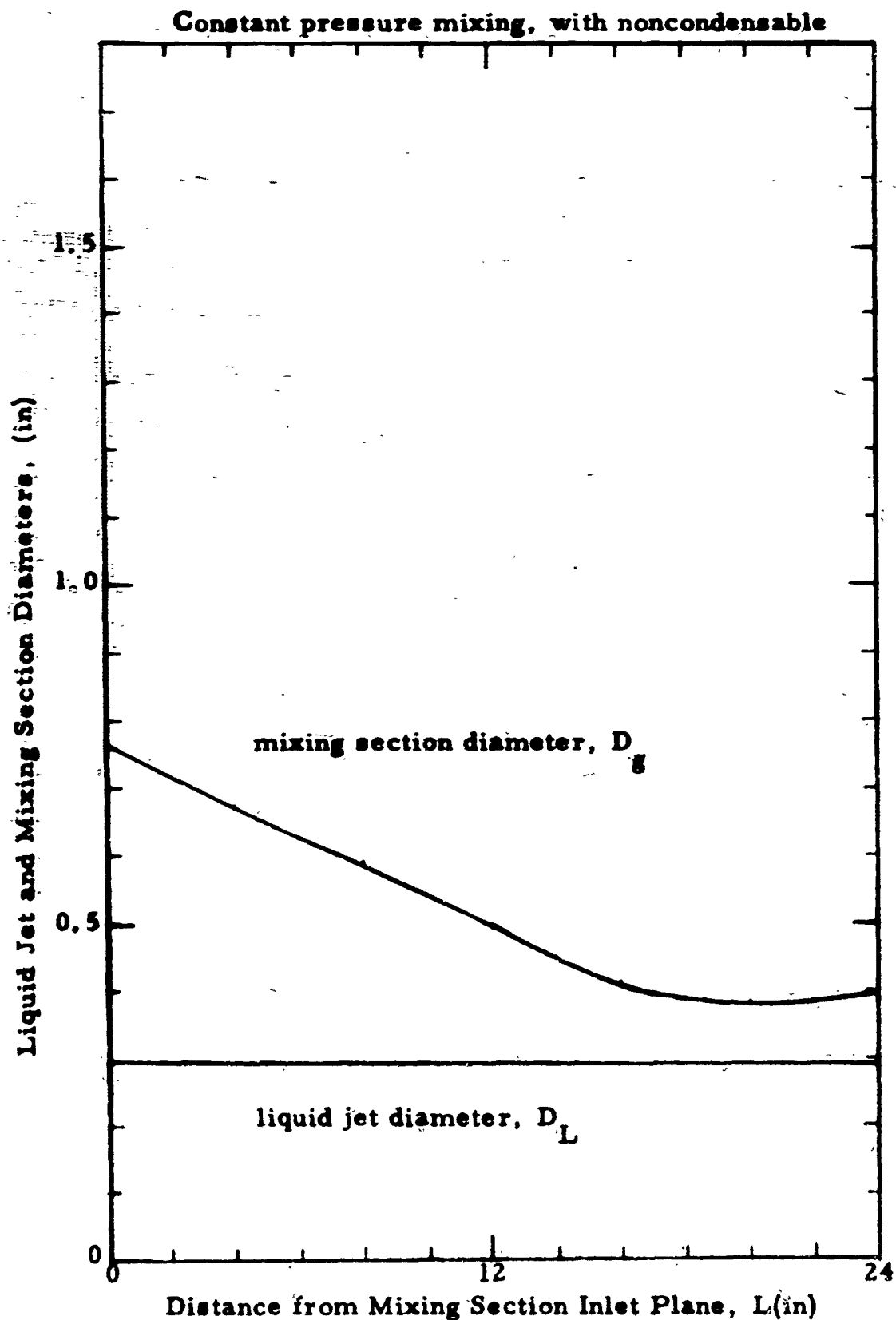


FIGURE 14 - LIQUID JET AND MIXING SECTION DIAMETERS VERSUS DISTANCE FROM MIXING SECTION INLET PLANE - MODEL IIa

$p_{go} = 94.5$ psia	$T_{go} = 340.0$ F	$\omega_o = 21.24$
$p_{Lo} = 325.0$ psia	$T_{Lo} = 40.0$ F	$\phi_o = 0.838$
$p_1 = 90.0$ psia	$D_{L1} = 0.295$ in	No. of Jets = 1.0

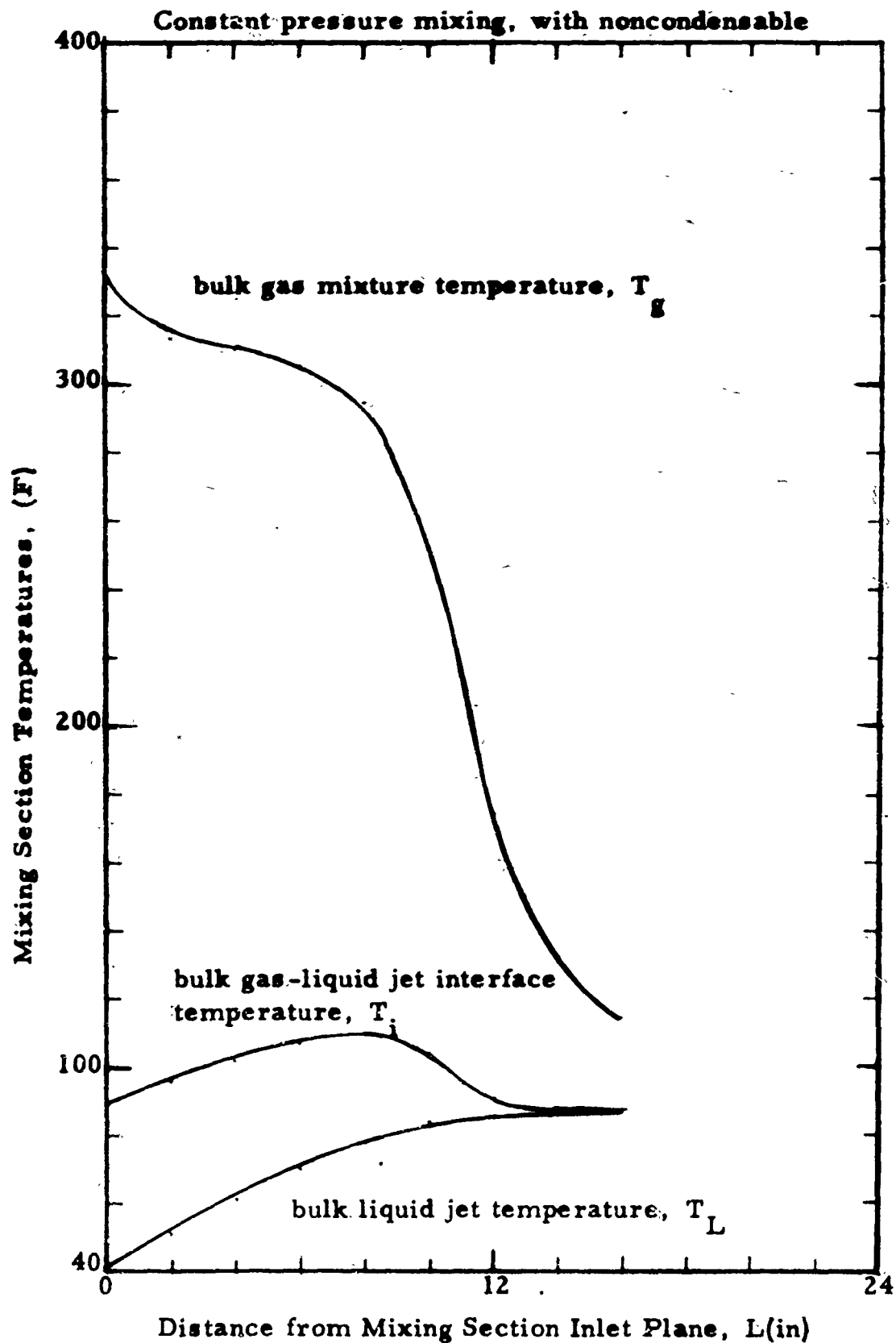


FIGURE 15 - VARIOUS MIXING SECTION TEMPERATURES
VERSUS DISTANCE FROM MIXING SECTION INLET PLANE -
MODEL IIb

$P_{go} = 94.5$ psia	$T_{go} = 340.0$ F	$\omega_o = 21.24$
$P_{Lo} = 325.0$ psia	$T_{Lo} = 40.0$ F	$\phi_o = 0.838$
$P_1 = 90.0$ psia	$D_{L1} = 0.295$ in	No. of Jets = 1.0

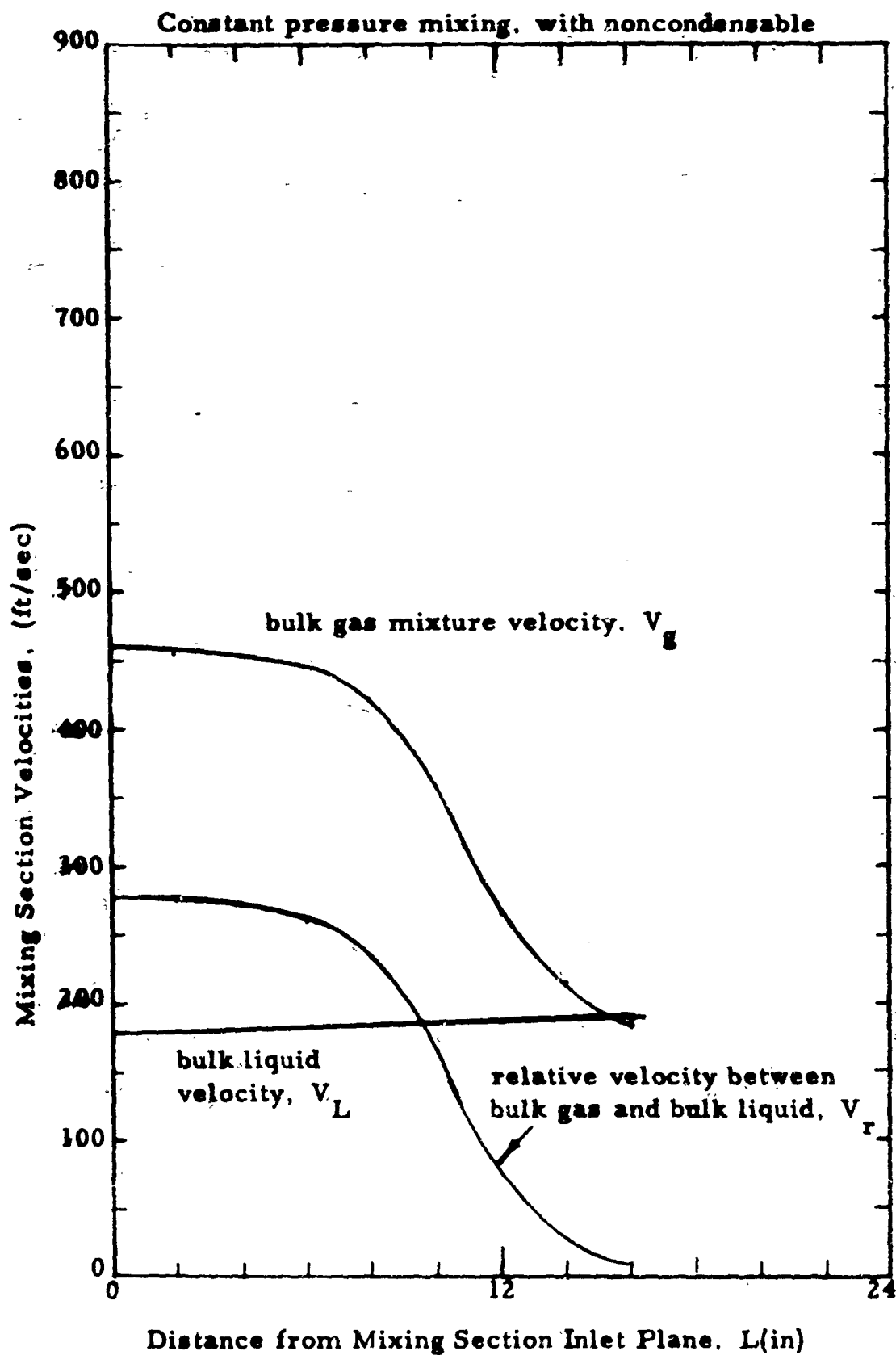


FIGURE 16 - VARIOUS MIXING SECTION VELOCITIES
VERSUS DISTANCE FROM MIXING SECTION INLET
PLANE - MODEL IIb

$$p_{go} = 94.5 \text{ psia}$$

$$p_{Lo} = 325.0 \text{ psia}$$

$$p_1 = 90.0 \text{ psia}$$

$$T_{go} = 340.0 \text{ F}$$

$$T_{Lo} = 40.0 \text{ F}$$

$$D_{L1} = 0.295 \text{ in}$$

$$\omega_o = 21.24$$

$$\phi_o = 0.838$$

$$\text{No. of Jets} = 1.0$$

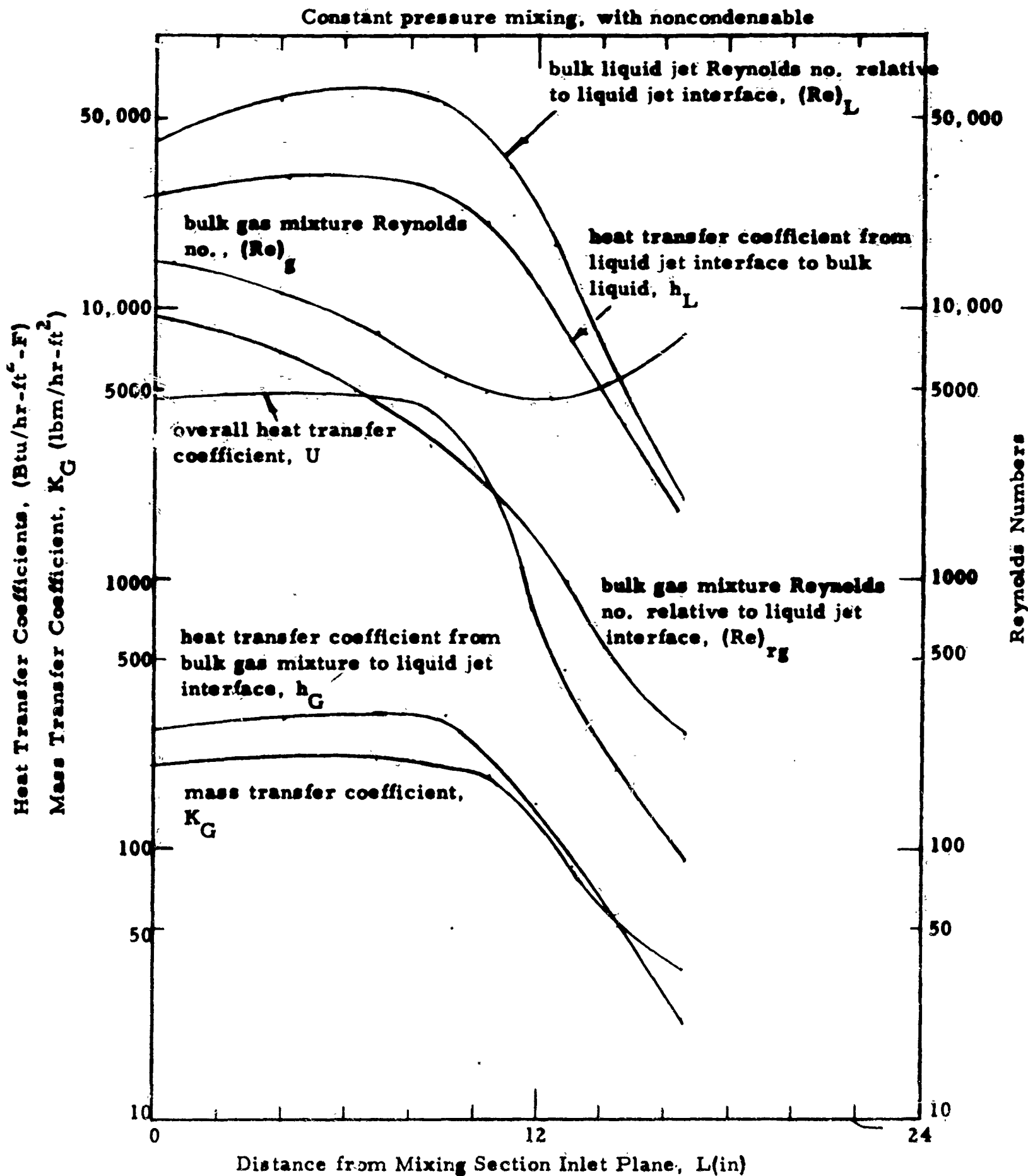


FIGURE 17 - VARIOUS REYNOLDS NUMBERS, HEAT TRANSFER COEFFICIENTS, AND MASS TRANSFER COEFFICIENT VERSUS DISTANCE FROM MIXING SECTION INLET PLANE - MODEL IIb

P_{go}	$= 94.5$ psia	T_{go}	$= 340.0$ F	ω_o	$= 21.24$
P_{Lo}	$= 325.0$ psia	T_{Lo}	$= 40.0$ F	ϕ_o	$= 0.838$
P_1	$= 90.0$ psia	D_{L1}	$= 0.295$ in	No. of Jets $= 1.0$	

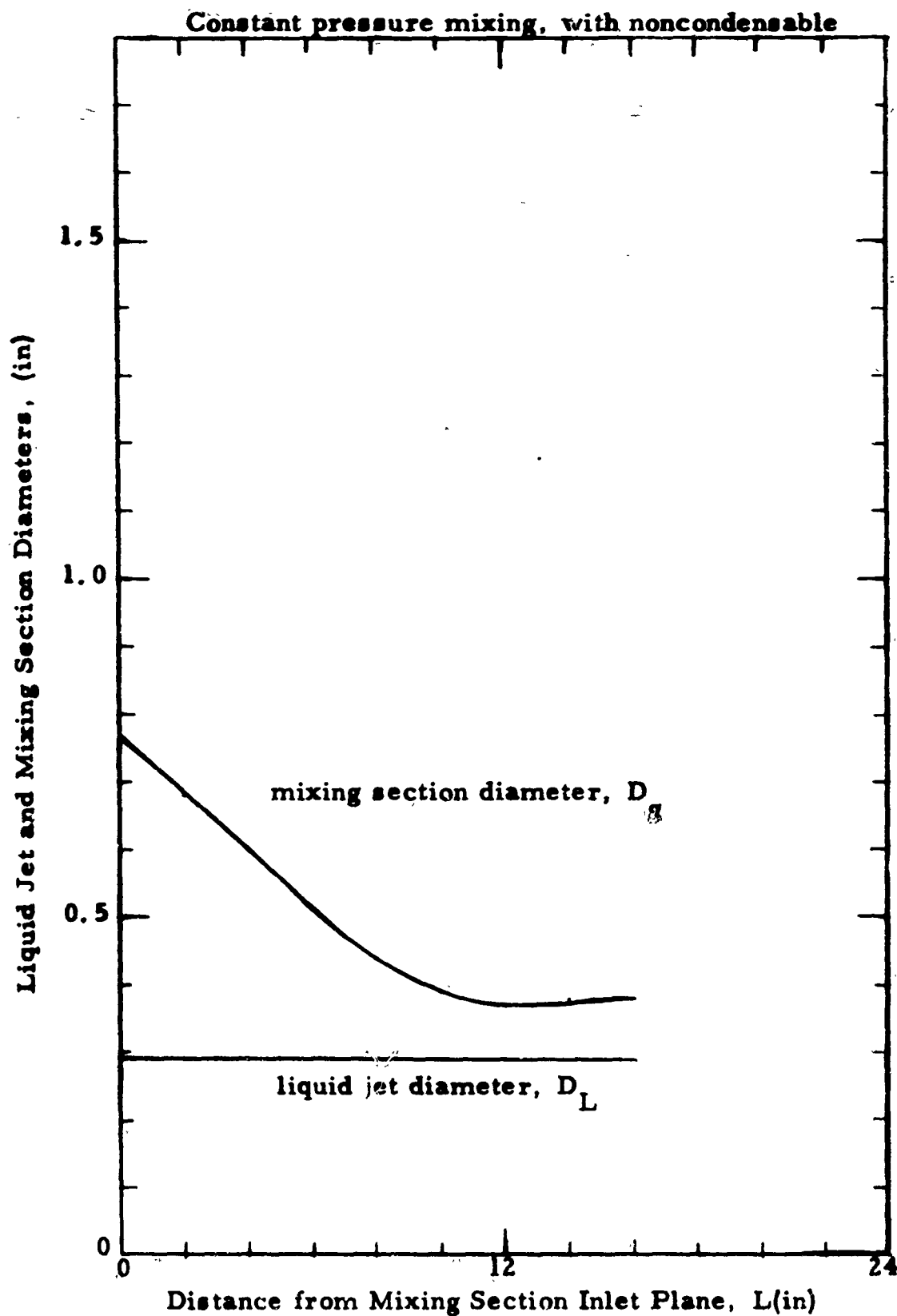


FIGURE 18 - LIQUID JET AND MIXING SECTION DIAMETERS VERSUS DISTANCE FROM MIXING SECTION INLET PLANE - MODEL IIb

$p_{go} = 94.5 \text{ psia}$	$T_{go} = 340.0 \text{ F}$	$\omega_o = 21.25$
$p_{Lo} = 325.0 \text{ psia}$	$T_{Lo} = 40.0 \text{ F}$	$\phi_o = 0.838$
$p_1 = 89.7 \text{ psia}$	$D_{L1} = 0.295 \text{ in}$	No. of Jets = 1.0

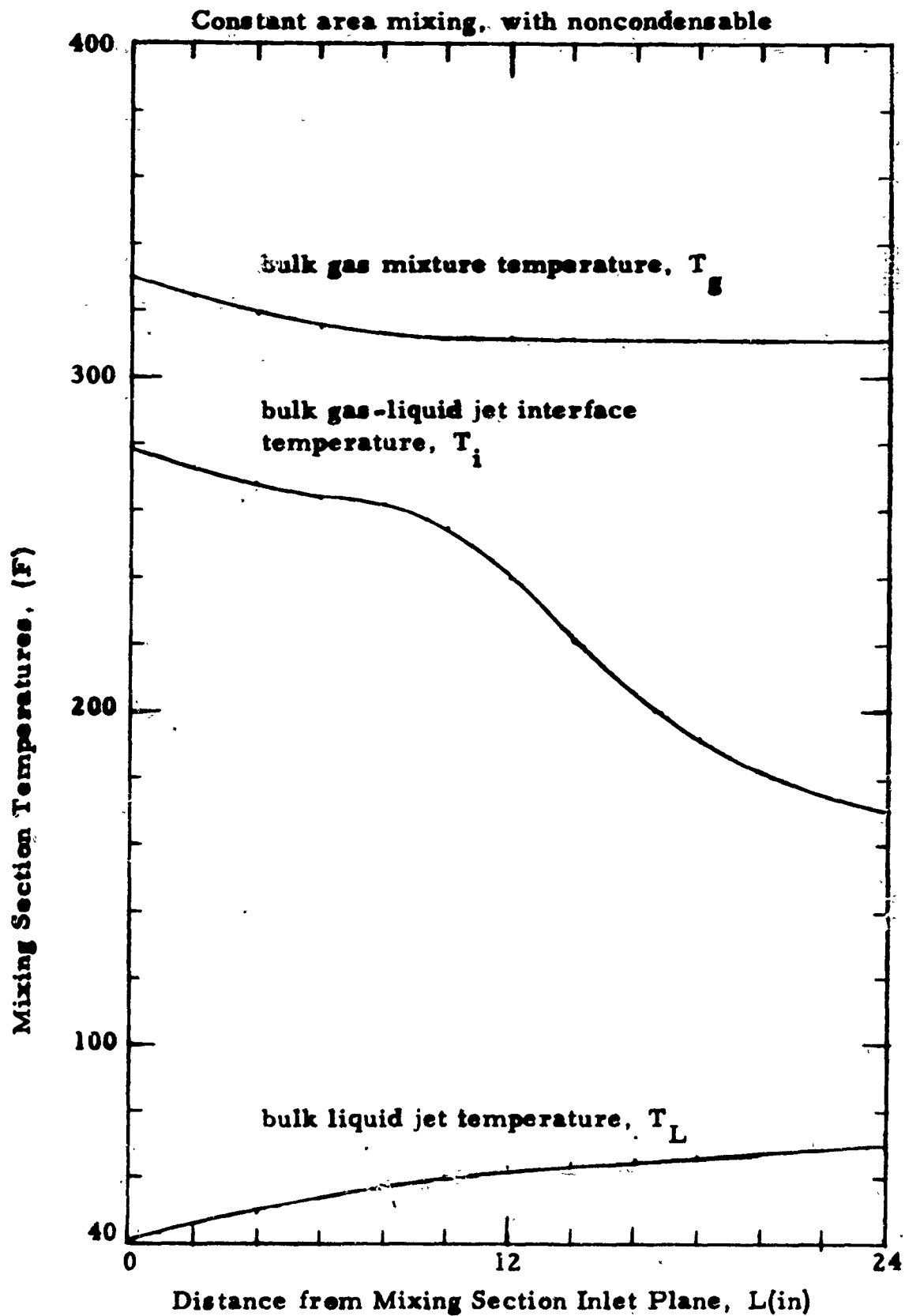


FIGURE 19 - VARIOUS MIXING SECTION TEMPERATURES
VERSUS DISTANCE FROM MIXING SECTION INLET PLANE -
MODEL III

$P_{go} = 94.5 \text{ psia}$ $T_{go} = 340.0 \text{ F}$ $\omega_o = 21.25$
 $P_{Lo} = 325.0 \text{ psia}$ $T_{Lo} = 40.0 \text{ F}$ $\phi_o = 0.238$
 $P_i = 89.7 \text{ psia}$ $D_{Li} = 0.295 \text{ in}$ No. of Jets = 1.0

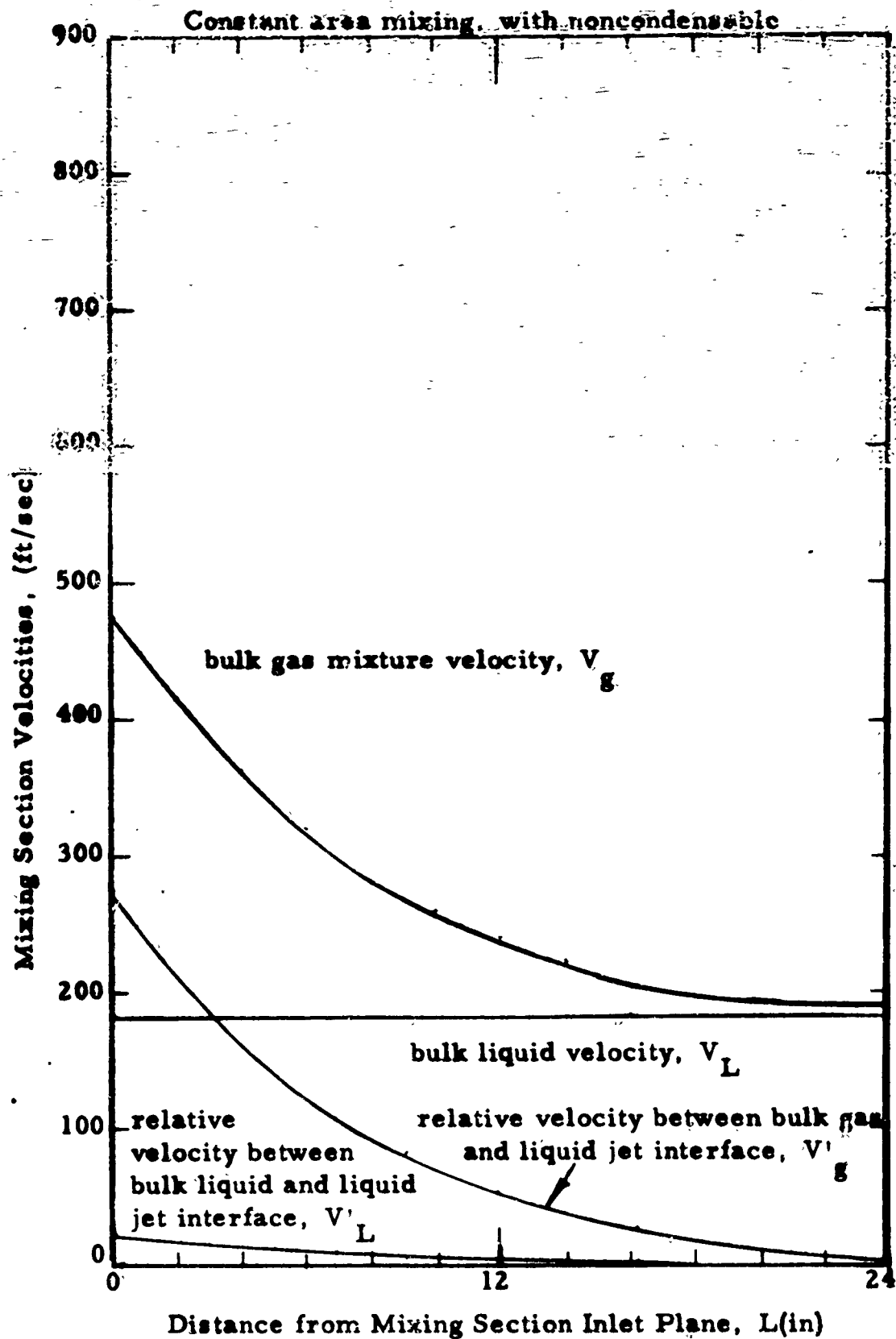


FIGURE 20 - VARIOUS MIXING SECTION VELOCITIES VERSUS DISTANCE FROM MIXING SECTION INLET PLANE - MODEL III

$$P_{g0} = 94.5 \text{ psia}$$

$$T_{g0} = 340.0 \text{ F}$$

$$\omega_0 = 21.25$$

$$P_{L0} = 325.0 \text{ psia}$$

$$T_{L0} = 40.0 \text{ F}$$

$$\phi_0 = 0.838$$

$$P_1 = 89.7 \text{ psia}$$

$$D_{L1} = 0.295 \text{ in}$$

$$\text{No. of Jets} = 1.0$$

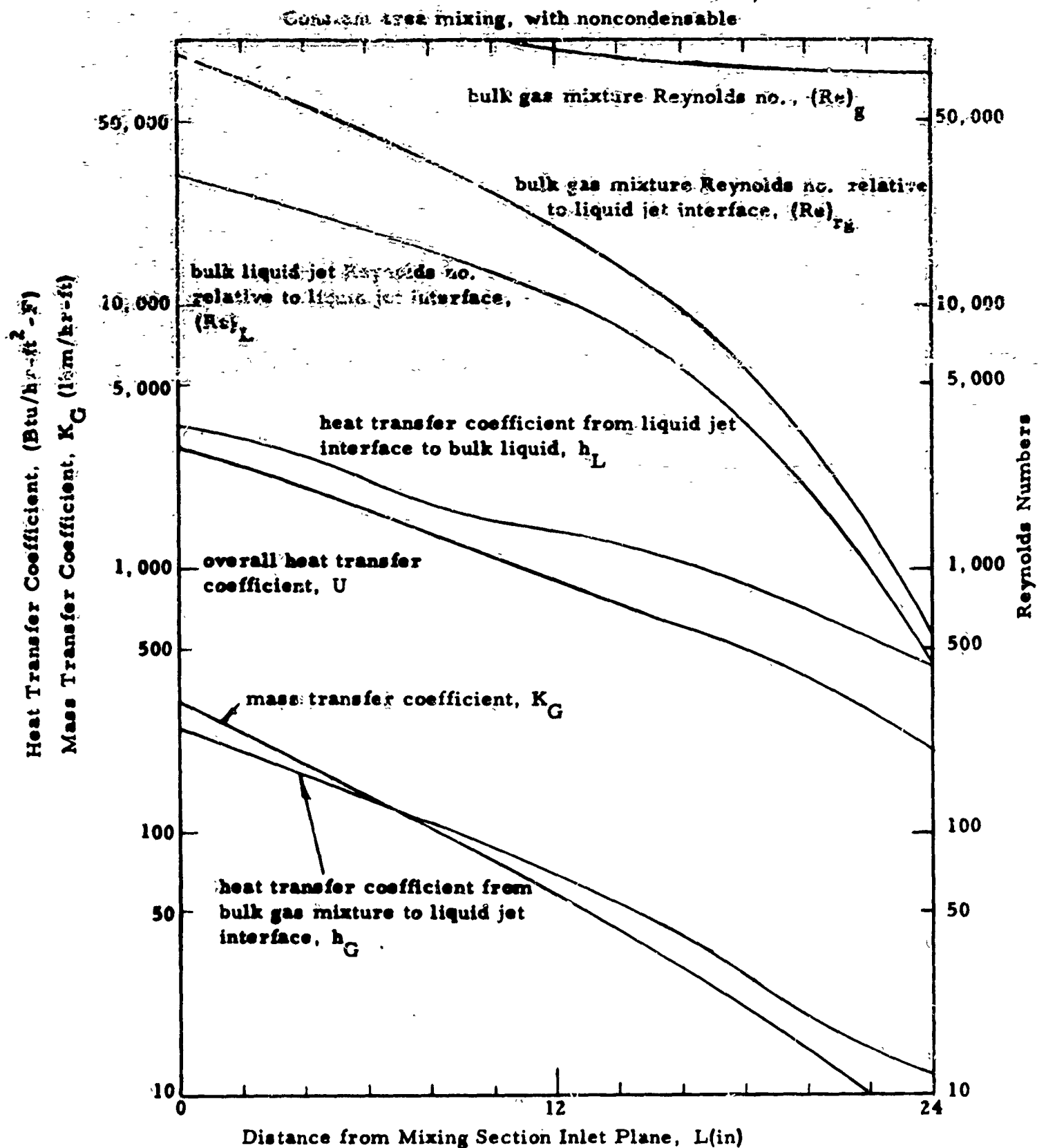


FIGURE 21 - VARIOUS REYNOLDS NUMBERS, HEAT TRANSFER COEFFICIENTS, AND MASS TRANSFER COEFFICIENT VERSUS DISTANCE FROM MIXING SECTION INLET PLANE - MODEL III

$p_{go} = 94.5 \text{ psia}$	$T_{go} = 340.0 \text{ F}$	$\omega_o = 21.25$
$p_{Lo} = 325.0 \text{ psia}$	$T_{Lo} = 40.0 \text{ F}$	$\phi_o = 0.838$
$p_1 = 89.7 \text{ psia}$	$D_{L1} = 0.295 \text{ in}$	No. of Jets = 1.0

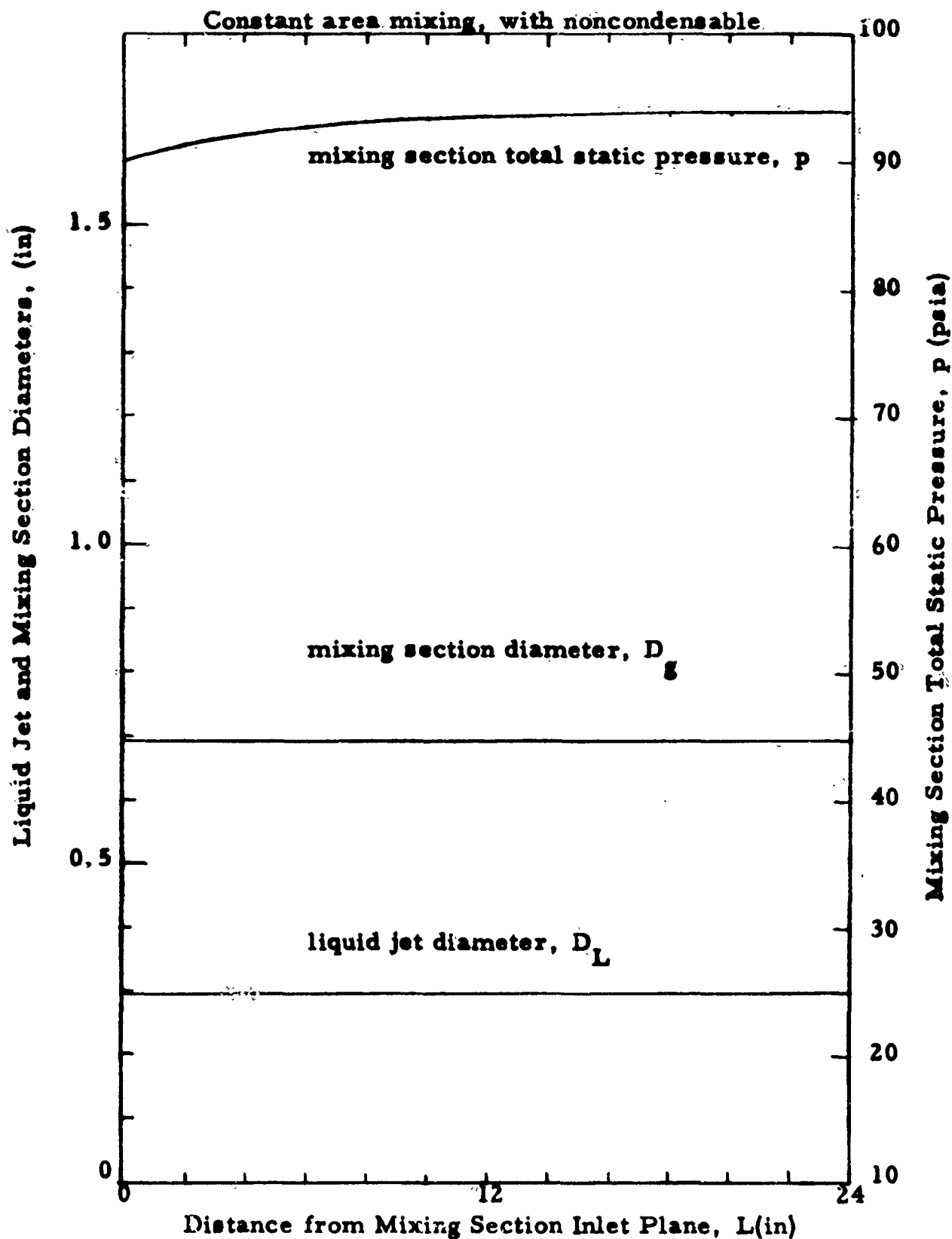


FIGURE 22 - LIQUID JET DIAMETER, MIXING SECTION DIAMETER, AND TOTAL STATIC PRESSURE VERSUS DISTANCE FROM MIXING SECTION INLET PLANE - MODEL III

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$P_{Lo} = 325.0$ psia	$T_{Lo} = 40.0$ F	$\phi_o = 0.858$
$P_1 = 90.0$ psia	$D_{L1} = 0.295$ in	No. of Jets = 1.0
$T_{go} = 500.0$ F	$\omega_o = 21.24$	

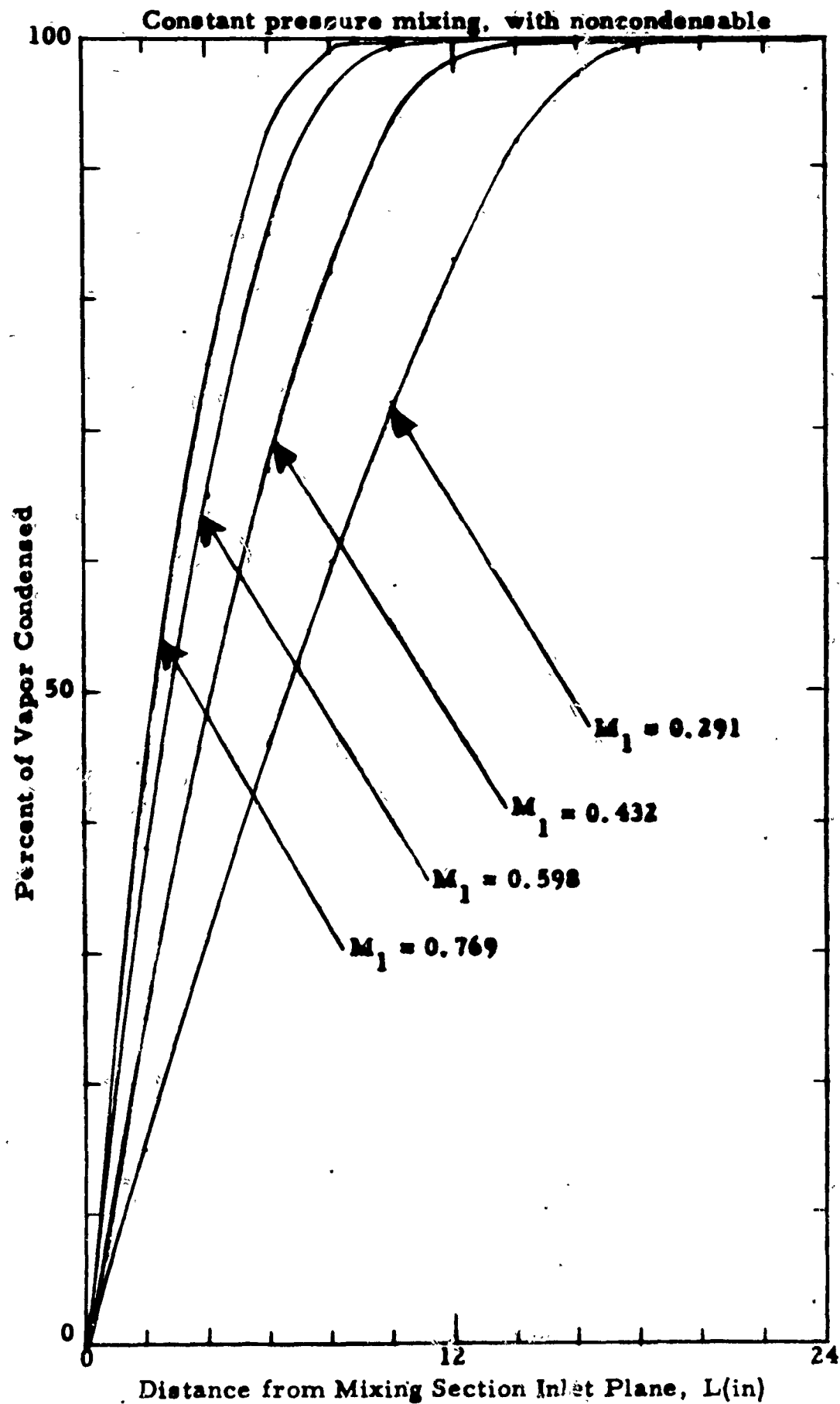


FIGURE 23 - PERCENT OF VAPOR CONDENSED VERSUS DISTANCE FROM MIXING SECTION INLET PLANE FOR VARIOUS INLET MACH NUMBERS - MODEL IIa

$p_{g0} = 94.5 \text{ psia}$ $T_{g0} = 340.0 \text{ F}$ $\omega_0 = 21.24$ $p_{L0} = 325.0 \text{ psia}$ $T_{L0} = 40.0 \text{ F}$

No. of Jets = 1.0

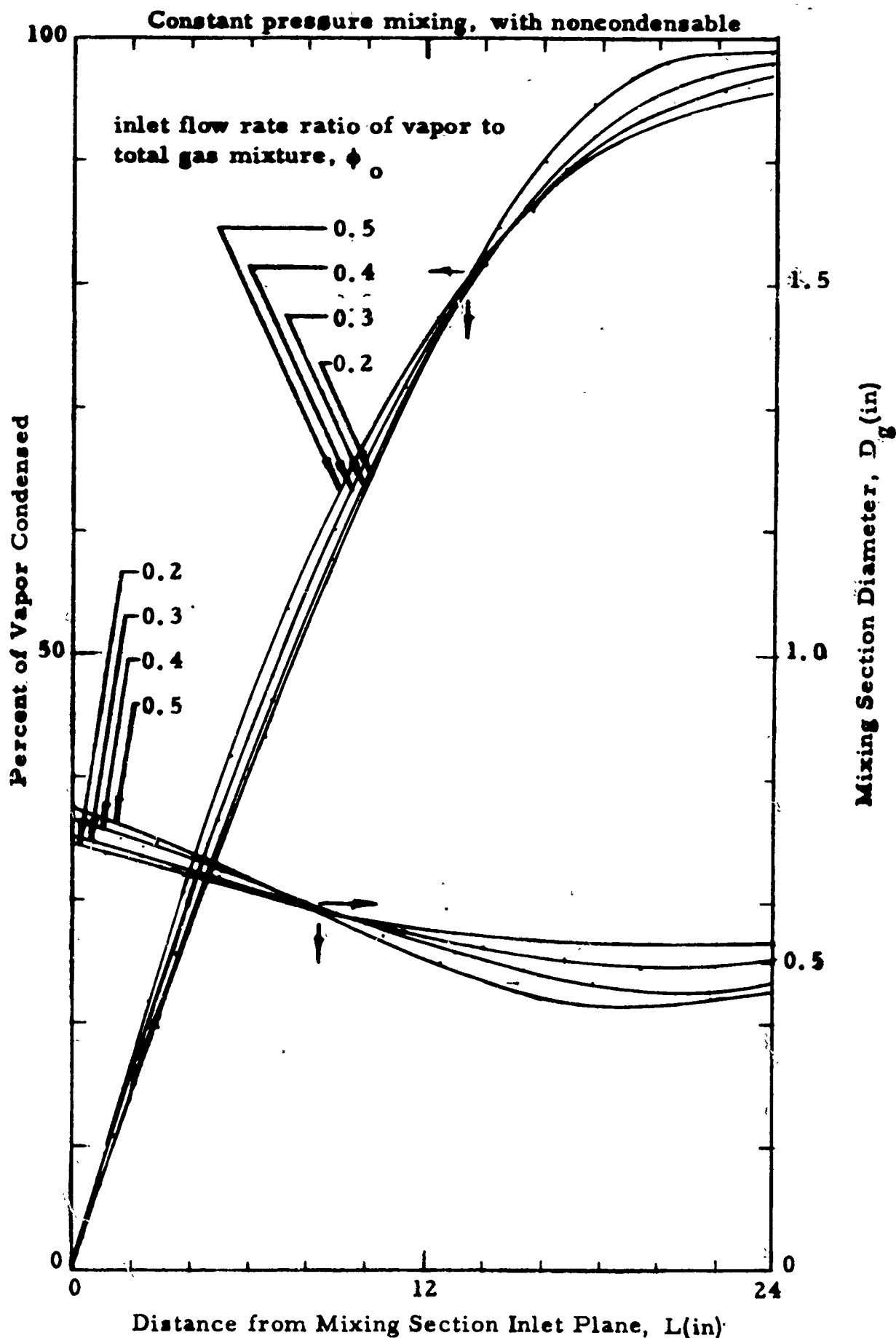
 $p_1 = 90.0 \text{ psia}$ $D_{L1} = 0.295 \text{ F}$ 

FIGURE 24 - PERCENT OF VAPOR CONDENSED AND MIXING SECTION DIAMETER VERSUS DISTANCE FROM MIXING SECTION INLET PLANE FOR VARIOUS INLET FLOW RATE RATIOS OF VAPOR TO TOTAL GAS MIXTURE - MODEL IIa

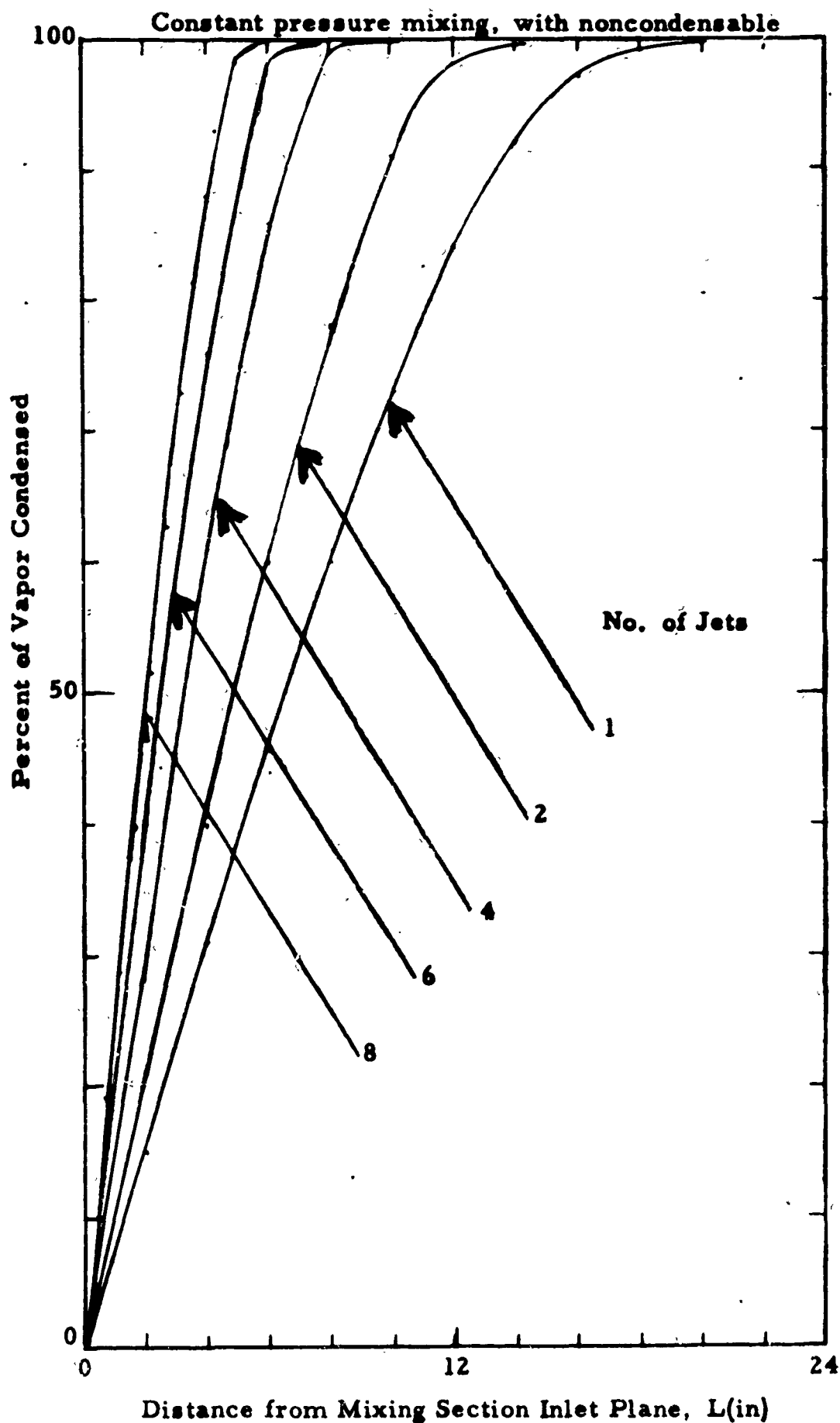
$p_{go} = 94.5 \text{ psia}$ $T_{go} = 340.0 \text{ F}$ $\omega_o = 21.24$ $p_{Lo} = 325.0 \text{ psia}$ $T_{Lo} = 40.0 \text{ F}$ $\phi_o = 0.838$ $p_1 = 90.0 \text{ psia}$ 

FIGURE 25 - PERCENT OF VAPOR CONDENSED VERSUS DISTANCE FROM MIXING SECTION INLET PLANE FOR VARIOUS NUMBERS OF LIQUID JETS - MODEL IIa

Input Data:

Model	Reference
I	Figures 7-10
IIa	Figures 11-14
IIb	Figures 15-18
III	Figures 19-22

No. of Jets = 1.0

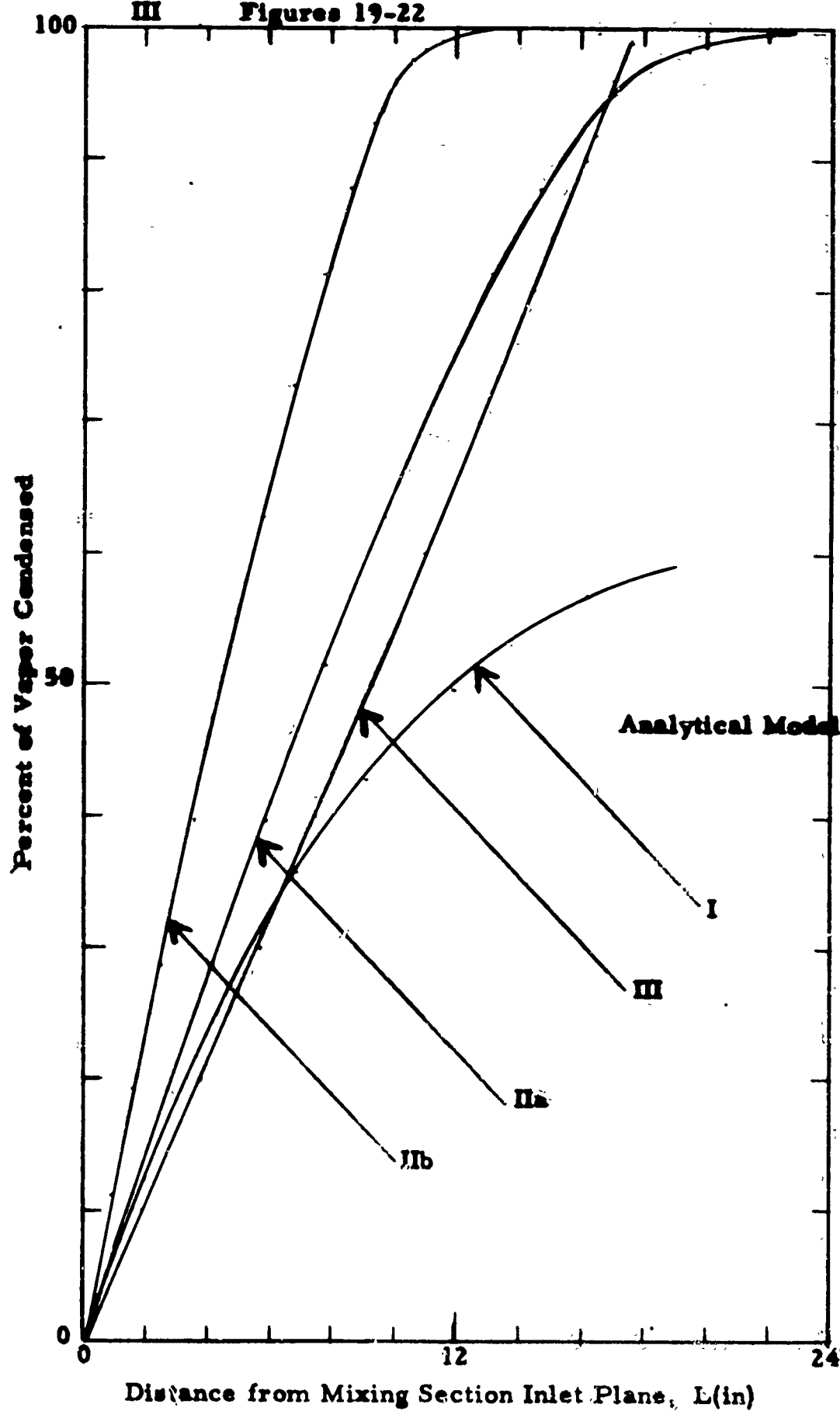


FIGURE 26 - PERCENT OF VAPOR CONDENSED VERSUS DISTANCE FROM MIXING SECTION INLET PLANE FOR VARIOUS ANALYTICAL MODELS

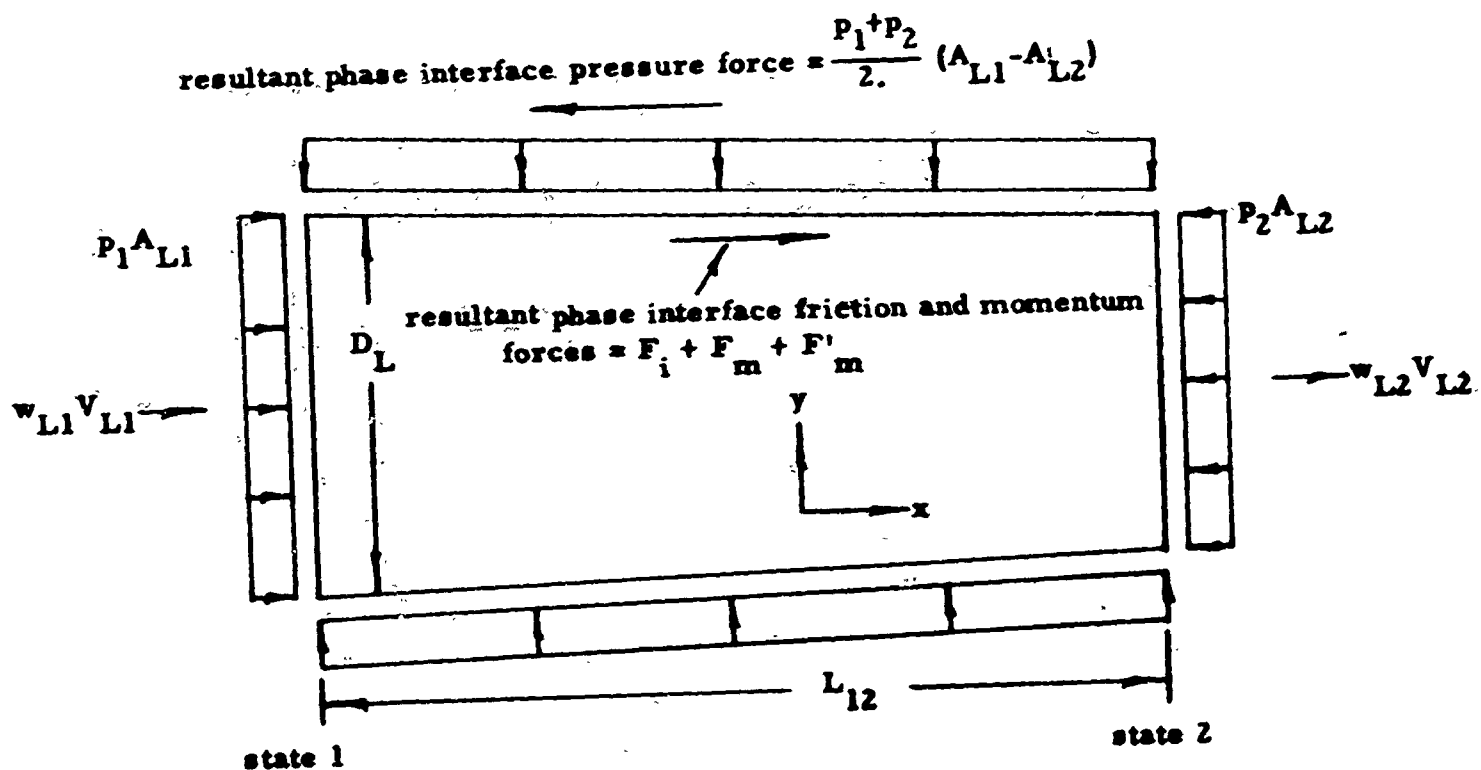


FIGURE 27a - LIQUID JET CONTROL VOLUME

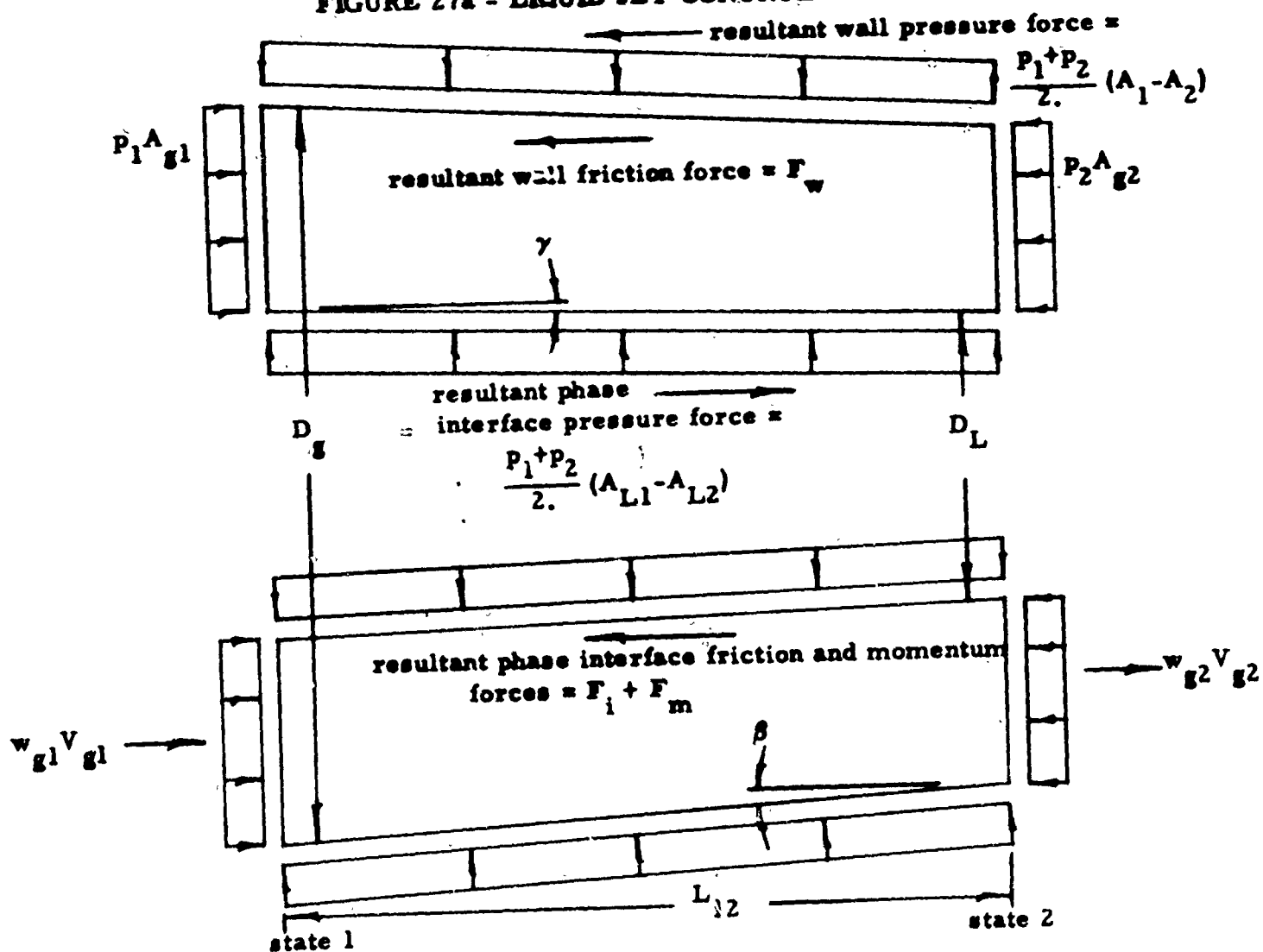


FIGURE 27b - GAS MIXTURE CONTROL VOLUME



MIXING SECTION

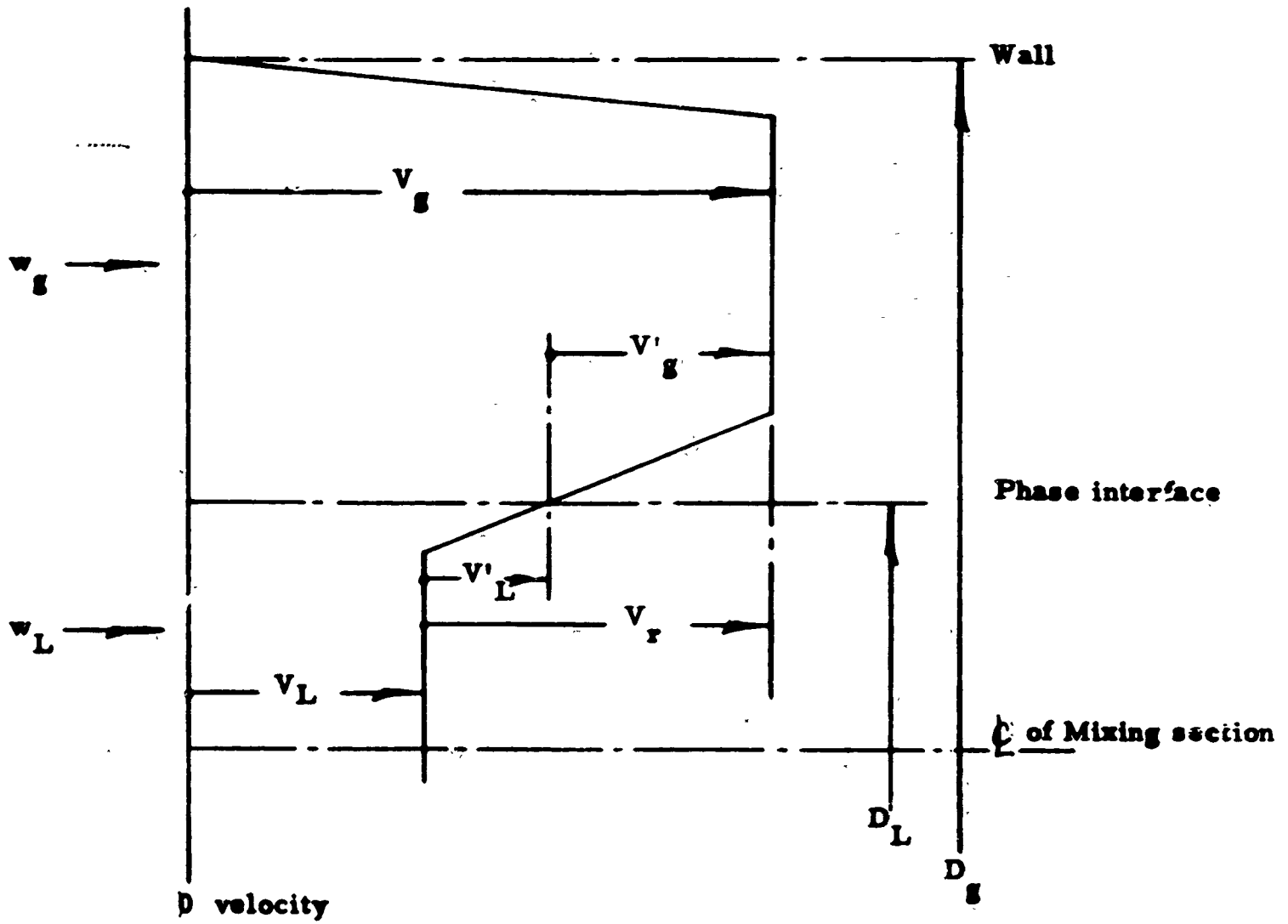


FIGURE 28 - ASSUMED VELOCITY PROFILE IN MIXING SECTION

REFERENCES

1. "Two-Phase Two-Component Flow in an Ejector with Condensation", M.A. Rivas, Jr., ScD Thesis, Massachusetts Institute of Technology, 1954.
2. "Condensuctor for Deep Running Torpedo, Part I: General Analysis and Calculated Performance", J. Kaye, E.F. Kurtz, Jr., S.W. Gouse, Jr., Report N-2, October 1, 1956, Joseph Kaye & Company, Inc., Cambridge, Mass.
3. "An Analysis of NUOS Condensuctor Test Data with a New Theory for the Variable Area Condensuctor", G.A. Brown, Report 44, 1961, Joseph Kaye & Company, Inc., Cambridge, Mass.
4. "Condensuctor, A Back Pressure Reduction Device" (Confidential), G.A. Brown, J. Sirmalis, Annual Meeting, ARS, November, 1962; Also TM 288, U. S. Naval Underwater Ordnance Station, Newport, Rhode Island, December, 1962.
5. "An Analytical and Experimental Investigation of a Condensing Ejector with a Condensable Vapor", J. Miguel, G.A. Brown, AIAA Paper 64-469, June, 1964, Washington, D. C.
6. "Diagnostic Analysis of the Diffusing Section of a Condensuctor", S.W. Gouse, Jr., J. Leigh, TM 101-27, January, 1964, Joseph Kaye & Company, Inc., Cambridge, Mass.
7. "Atomization and Spray Drying", W.R. Marshall, Jr., Chemical Engineering Progress Monograph Series, No. 2, Vol. 50, 1954, Published by American Institute of Chemical Engineers.
8. "Theoretical and Experimental Study on Atomization of Liquid Drop in High Speed Gas Stream", N.M. Isshiki, Report of Transportation Technical Research Institute, Report No. 35, Published by the Unyu-Gijutsu Kenkyujo Mejino, Toshima-Ku, Tokyo, Japan, July, 1959.
9. "The Atomization of Liquid Fuels", E. Giffen and A. Muraszew, pp. 2-3, John Wiley & Sons, Inc., 1953.
10. "Nozzle Sprays in Air Streams", M.A. Weiss, C.H. Worsham, Chemical Engineering Science (Genie Chimique), Vol. 16, Nos. 1 & 2, pp. 1-6, 1961.

11. "Correlation of Experimental Data on the Disintegration of Liquid Jets", C.C. Miesse, Ind. and Eng. Chemistry, Vol. 47, No. 9, pp. 1690-1701, September, 1955.
12. "Breakup of Liquid Jets by Transverse Shocks", G. Morrell, 8th Symposium (International) on Combustion, 1962.
13. "Mechanism of the Atomization of Liquid", R.S. Castleman, Jr., Bureau of Standards, Journal of Research, Vol. 6, pp. 369-376, 1931.
14. "The Theory of Turbulent Jets", G.N. Abramovich, M.I.T. Press, Cambridge, Mass., 1963.
15. "Physiochemical Hydrodynamics", Veniamin G. Levich, Prentice Hall, Inc., 1962.
16. "Investigation of Condensers Applicable to Space Power Systems, Part II Jet Condensers", Electro-Optical Systems, Inc., Pasadena, California, Prepared for NASA, Contract NAS7-11, 1588-Final, 30 November 1962.
17. "Effect of a Noncondensable Gas on the Size of a Hull Type Condenser for Use in Underwater Ordnance," S. W. Gouse, Jr., Report 49, Joseph Kaye & Company, Inc., Cambridge, Mass., January 12, 1963.
18. "Design of Cooler Condensers for Mixtures of Vapors with Non-condensing Gases", A.P. Colburn and O.A. Hougen, Industrial and Engineering Chemistry, Vol. 26, No. 11, pp. 1178-1182, 1934.
19. "Process Heat Transfer", D.Q. Kern, McGraw-Hill Book Company, 1950.
20. "Heat Transmission", W.H. McAdams, Third Edition, McGraw-Hill Book Company, 1954.
21. "Thermodynamic Properties of Steam", J.H. Keenan and F.G. Keyes, John Wiley & Sons, Inc., 1936.
22. "Chemical Engineer's Handbook", J.H. Perry, Editor, McGraw-Hill Book Company, 1950.
23. "Molecular Theory of Gases and Liquids", J.O. Hirshfelder, C.F. Curtiss, and R.B. Bird, John Wiley & Sons, Inc., 1954.
24. "The Properties of Gases and Liquids", R.C. Reid and T.K. Sherwood, McGraw-Hill Book Company, 1958.

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